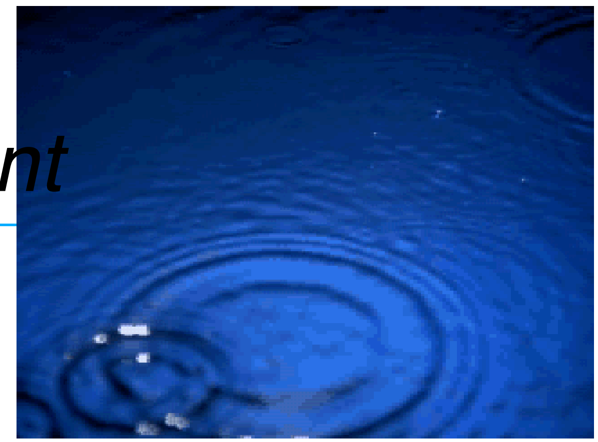
Global Precipitation Measurement



System Definition Review
Core Spacecraft Requirements

December 6-8, 2005

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Goddard Space Flight Center

- **GPM Core Spacecraft Requirements Parentage**
  - *GPM Mission Requirements Flow*
  - *GPM Requirements Documentation Tree*
  - *Core Spacecraft L2_L3 Requirements Traceability*
- **GPM Core Spacecraft L2 Driving Requirements**
- **GPM Core Spacecraft L3 Requirements Overview**
  - *Avionics Package Requirements*
- **Supplemental Slides**
  - *Requirements, Design Details*

GPM Mission Requirements Flow

Level I Requirements

Mission:
- Measurement
- Validation
- Products
- Duration

Instrument:
- Space Based
- Ground Based

- Launch
- Science Data Science
- Science Products
- Operations
- Public Outreach

Other Sources

- Formulation Study Results
- Science Workshops
- GSFC Guidelines

Level II Requirements

Science:
- Precipitation Types
- Measurements
- Coverage
- Frequency & Accuracy

Mission:
- Data Handling
- Payloads
- Constellation Design
- Calibration & Verification
- Outreach

- Instruments
  - DPR
  - GMI
- Core Spacecraft
  - Performance
  - Accommodation
- Constellation Spacecraft
  - Performance
  - Accommodation

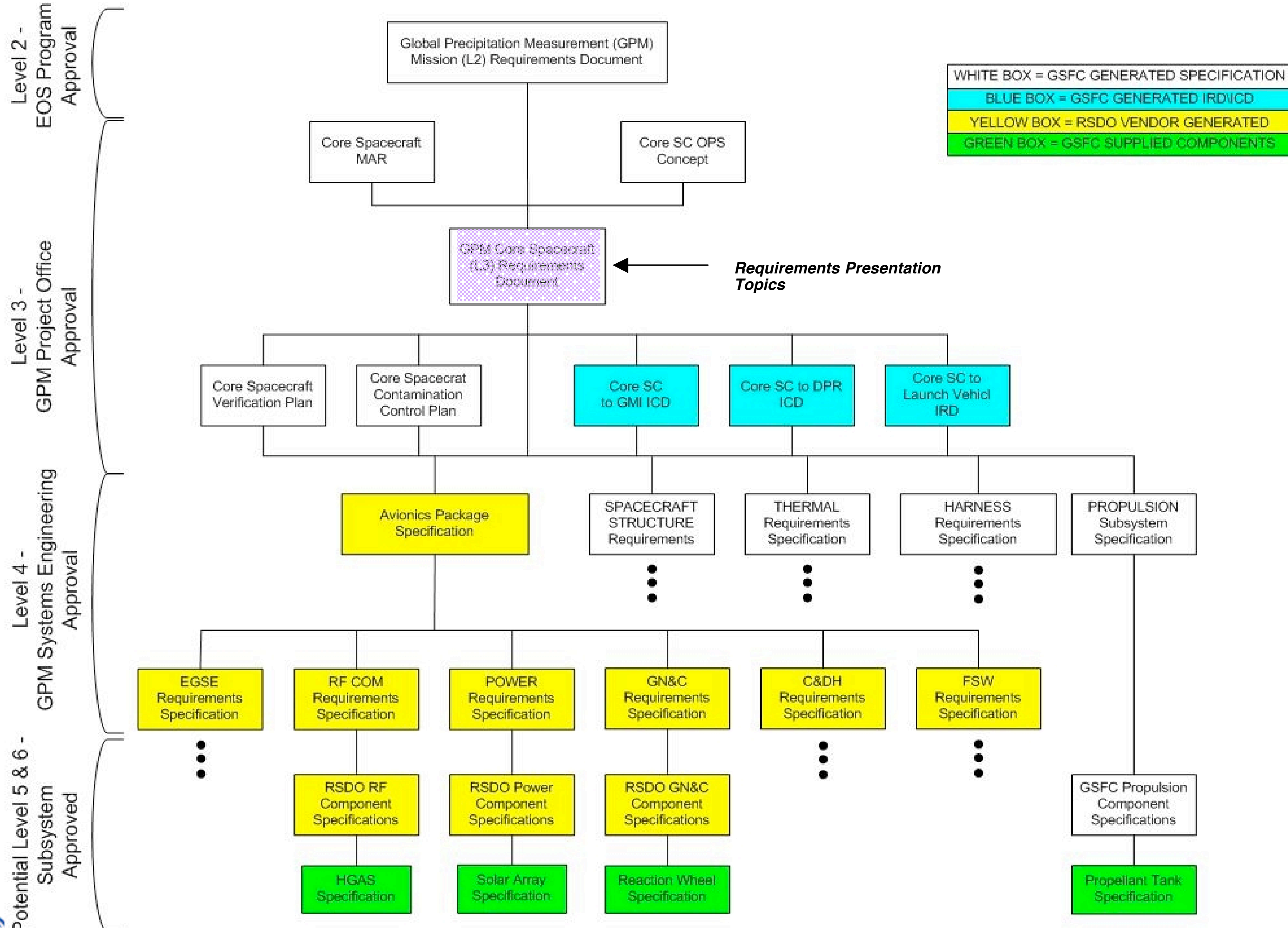
Ground Segment:
- NASA Mission Operations
  - S/C Flight Ops
  - Space/Ground Coordination
- Ground Validation & Calibration
- Precipitation Processing System
  - Product Development
  - Data Distribution & Archive

Level III Requirements

- GPM Core Spacecraft (L3) Performance Specification, (422 -40 - 03 -001)

Note: Light text signifies Core spacecraft Level 3

GPM Requirements Documentation Tree



GPM Core Spacecraft Driving Requirements

- ***(L2: 5.10.2) Instrument Accommodation Requirements***
  - *Dual Frequency Precipitation Radar (DPR) – provided by JAXA*
  - *GPM Microwave Imager (GMI)*
- ***(L2: 5.12.1) Launch Vehicle***
  - *JAXA provided H2A-202*
- ***(L2: 2.2.1; 5.1) Core Spacecraft Launch Readiness Date***
  - *December, 2010*
- ***(L2: 5.5) Mission Orbit - DPR operational requirement***
- ***(L2: 5.3) Spacecraft Lifetime***
  - *3 years with consumables sized for 5 years*
- ***(L2: 2.2.11) Data Collection Efficiency***
  - *Collect science data from each primary instrument at least 95% of time*
- ***(L2: 3.3.2) Immediate Data Products***
  - *Provide Level 0 Products with data latency less than three (3) hours.*
- ***(L2: 5.4) Probability of Success***
  - *A 0.90 quantitative reliability probability of success (P_s)*
- ***(L2: 2.2.6) EOL Re-entry Requirements***
  - *Comply with Debris Guidelines NPD8170.3, NSS 1740.14*
  - *Design for Demise*

- ***Core Spacecraft Requirements Traceability***
  - *Flowdown found in the matrix provided in supplemental slides at end of presentation*

Global Precipitation Measurement (GPM) Mission (L2) Requirements Document (420.2-REQS-013001A) GPM Mission Requirements

↓

GPM Core Spacecraft (L3) Performance Specification, (422-40-03-001)

Traceability Matrix Sample

	Level 2 Requirement		**Level 3 Requirennent**
2.2.1	Launch Readiness Date – Core Observatory	3.2.1	Observatory Launch Readiness Date
2.2.5	Mission Assurance Requirements	3.5	Mission Assurance Requirements
		3.6	Redundancy, Fault Tolerance and Safety Design Requirements
		3.6.1	Mission Failure - Single Fault Tolerance Design Requirements
		3.6.2	Safety Design Requirements
		3.6.2.1	Safety Failure-Tolerance Design Requirements
		3.6.2.2	Control of Hazardous Functions
		3.6.2.3	Design for Minimum Risk
		3.6.2.4	Industrial Safety Requirements
		3.7	GPM Core Spacecraft Reliability Design Requirements
		3.7.1	GPM Core Spacecraft Subsystem Reliability Design Requirements

Core Spacecraft (Level 3) Requirements Specification

- ***GPM Core Spacecraft Performance Specification, (GPM-422-40-03-001) contains current requirements for GPM Core Observatory including:***
  - *Section 3: Mission Orbit, Lifetime, Launch Vehicle Selection, Mission Operational States, General Requirements for Mission Assurance, Redundancy, Fault Tolerance, Safety and Reliability*
  - *Section 4: Instrument Complement Support Requirements*
  - *Section 5: Spacecraft Subsystem Functional Performance Requirements*
  - *Section 6: Space Environment Requirements including radiation, pressure, atomic oxygen, meteoroids, and orbital debris*
  - *Section 7: Integration, Test, and Ground Support Equipment as well as other design requirements*

- **3.1.1 Core Observatory Nominal Operating Orbit**
  - *Orbit altitude range (geodetic height) of 397 km to 419 km*

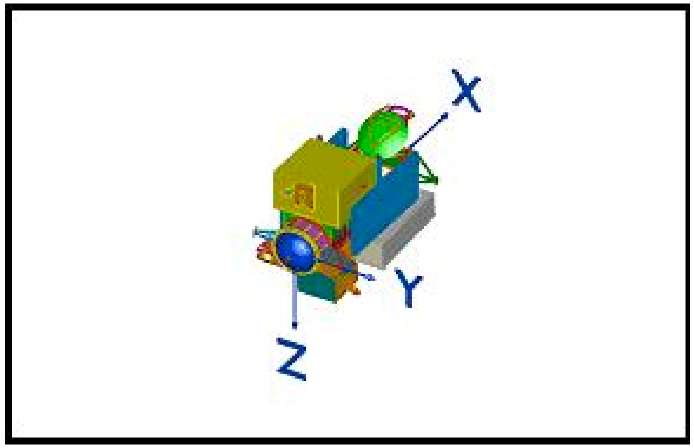
GPM Core Spacecraft Reference Orbit and Tolerances

Mean BLJ2 Keplerian Element	Nominal	Tolerance
Semi-Major Axis	6776.14 km	± 1.0 km
Eccentricity	0.0001	± 0.00022
Inclination	65.0 degrees	± 0.2 degrees

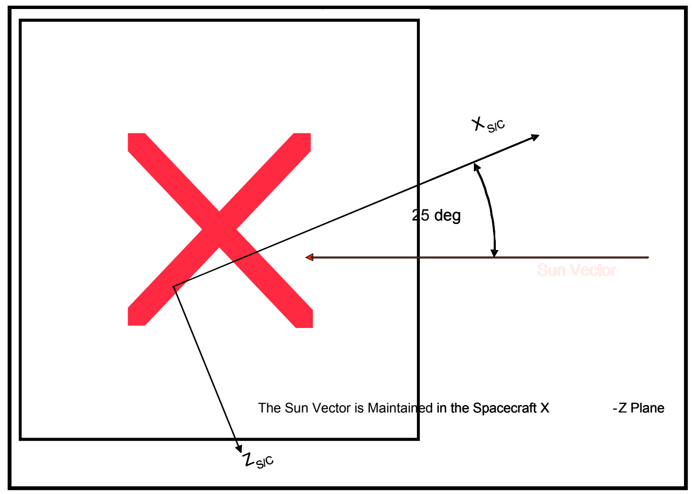
- ***3.3.2: Injection Orbit**:*
  - *400 ± 10 km by 650 ± 10 km*

Mission Attitude

- **3.1.2 Core Spacecraft Nominal Attitude**
  - +X axis parallel to orbital velocity vector (nominal launch configuration)
  - +Z axis parallel to Nadir vector, and
  - +Y axis normal to the orbital velocity vector according to the right hand rule



- **3.1.2.1 Solar Pointing Orientation**
  - The GPM Core Spacecraft shall employ a solar pointing orientation as needed for Safe Hold Mode, contingency operations, or other special operations
  - The solar pointing orientation for the GPM Core Spacecraft shall be defined as the spacecraft's +X axis offset +25.0 degrees (rotation about the spacecraft +Y axis when the sun vector is in the spacecraft XZ plane) from the solar vector and held fixed to the sun vector



Observatory Lifetime

- **3.2.2 Observatory Commissioning Phase**
  - *Not to exceed sixty (60) days*
    - *Maneuver to the mission orbit within fifteen (15) days of launch*
    - *45 days instrument checkout period*

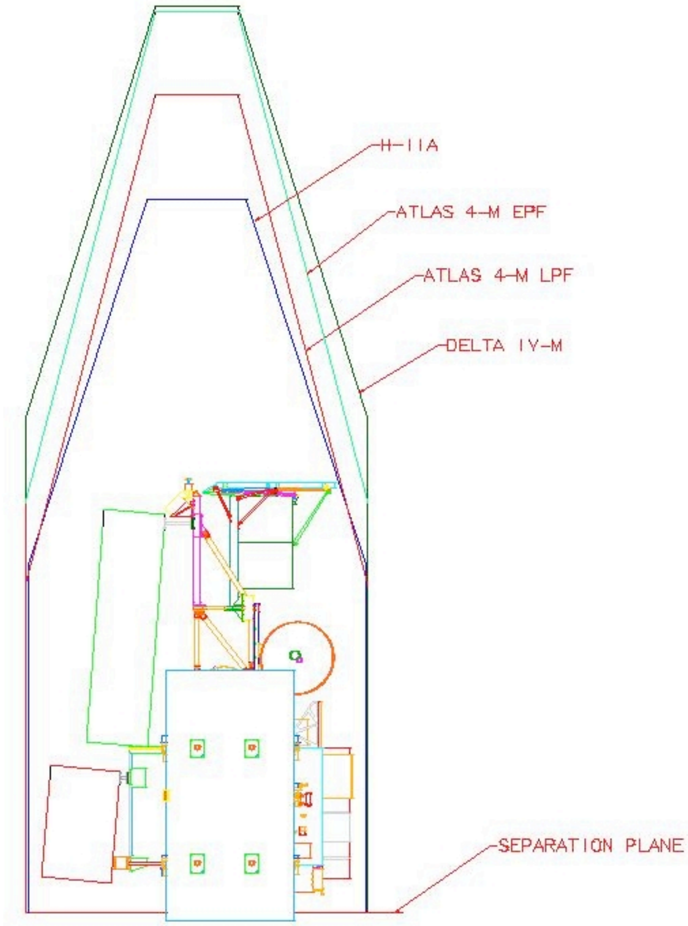
- **3.2.3 Core Observatory Operational Phase**
  - *Designed to operate for a minimum of 3 years with consumables sized to reach a 5-year goal*

- **3.2.4 Spacecraft Decommissioning (End-of-Life Disposal)**
  - *Conform to Guidelines in NPD 8710.3, and NSS 1740.14*

  - ***3.2.4.1.1 "Design-for-Demise" Philosophy***
    - *Core Spacecraft Observatory shall be designed to preclude the need for safe ocean disposal (i.e. designed for demise during re-entry) in accordance with NSS 1740.14*

Launch System

- ***Launch System Requirements***
  - *3.3.1 JAXA provided H2A-202 Expendable Launch Vehicle (ELV)*
  - *Launch from the Tanegashima Space Center (TnSC)*
  - *GPM Core Spacecraft to H2A-202 Launch Vehicle Interface Requirements Specification (GPM 422-40-03-100) contains current interfaces and concepts for launch vehicle operations for the GPM Core Observatory*
  - *3.3.5 Acquire the mission attitude, starting from any attitude and tip-off rates less than the following:*
    - *Pitch: ≤ 2.0 degrees/second (3_)*
    - *Yaw: ≤ 2.0 degrees/second (3_)*
    - *Roll: ≤ 0.5 degrees/second (3_)*
  - *3.3.3 Observatory mass not to exceed the launch vehicle allocated capability of 3200 kg.*



- ***Spacecraft configuration compatible with EELV and H-IIA fairings***

- ***3.4 GPM Core Spacecraft Modes of Operation:***

Mode	Sub-Mode	Purpose/Activity	Invoked	Attitude	Comm
3.4.1 Launch Mode		-Launch	Pre-launch to separation	n/a	none
3.4.2 Initial Orbit Acquisition Mode		-Initiate TLM -Deploy Arrays, HGA -Acquire power positive, thermal safe orientation	Separation to power positive, thermal safe state	Power positive	TDRSS-SA HGA Omni
3.4.3 Engineering Mode		-Subsystem checkout -Orbit maintenance -180° Yaw Maneuver	As needed	Nadir; Engineering Coarse Pointing (5.5.1.2.1)	TDRSS-SA HGA
3.4.4 Mission Mode		-Science Operations -Autonomous	›95% of time	Nadir; Mission Precision Pointing (5.5.1.2.1)	TDRSS-MA TDRSS-SA HGA
	3.4.4.2 Instrument Test and Calibration Sub-Mode	-90° Yaw Maneuver -Instrument calibration	As required for DPR cal	Nadir; Mission Precision Pointing (5.5.1.2.1)	TDRSS-MA TDRSS-SA HGA
3.4.5 Spacecraft Safe Hold Mode Supplemental Slide		-Safe spacecraft	Autonomously upon fault detection	Safe Attitude Nadir or Solar Contingent on Anomaly	TDRSS-SA Omni

- **3.5 Mission Assurance Requirements**
  - GPM Core Spacecraft Mission Assurance Requirements (GPM 422-40-01-004)

- **3.6.1 Redundancy / Fault Tolerance**
  - Redundancy consistent with the mission lifetime and reliability requirements
  - Reasonable trade-off with a capacity to recover from a single credible failure in hardware without loss of mission objectives

- **3.6.2 Safety Design Requirements**
  - NASDA-STD-14C (JMR-002) "Launch Vehicle Payload Safety Requirements and AFSPCMAN 91-710, “Air Force Space Command Range Safety Policies and Procedures”
    - 3.6.2.1 Launch Vehicle Payload Safety Requirements
    - 3.6.2.2 Safety Failure-Tolerance Design Requirements
    - 3.6.2.3 Control of Hazardous Functions
    - 3.6.2.4 Industrial Safety Requirements

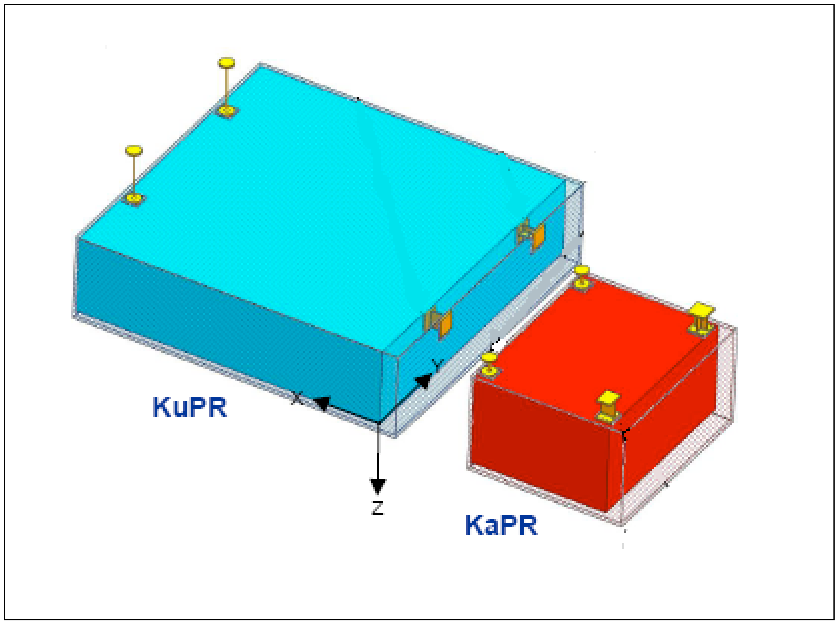
- ***3.7 GPM Spacecraft Reliability Design Requirement***
  - *A 0.90 quantitative reliability probability of success (P_s)*

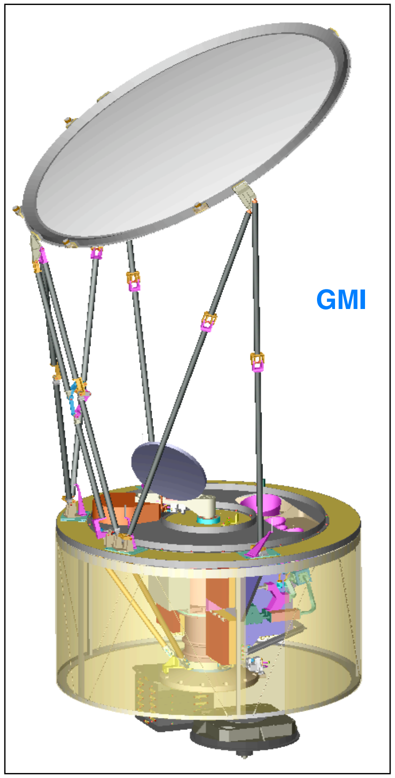
  - ***3.7.1 Spacecraft Subsystem Reliability Allocations***

Spacecraft Subsystem	Reliability
Structure and Mechanisms	0.98
Thermal	0.98
Power	0.98
Propulsion	0.99
Avionics Package	0.95

Instrument Suite Accommodation

- **4.0 Instrument Complement Support Requirements**
  - Dual Frequency Precipitation Radar (DPR)
  - GPM Microwave Imager (GMI)





Instrument FOV Geo-Location / DPR Co-Alignment

- ***4.2.1 Geo-Location of Instrument Science Measurements***

Instrument IFOV	Geo-Location Requirements
DPR	± 2.5 km (3 σ)
GMI	± 3.5 km (3 σ)

  - *Preliminary Geo-Location Budget in Supplemental Slides*

- ***4.2.2 Co-Alignment of KuPR and KaPR Instrument Science Data***
  - *Co-align IFOV centers of the two radars to within 1.0 km*
    - *Preliminary DPR Co-Alignment Budget in Supplemental Slides*

Instrument Complement Support Requirements

Instrument Resource Allocations

Instrument	Mass (kg) (4.3.1)	Power Orbital Average (W) (4.4.2)	Maximum Heat Flow (W) (4.5)
Ku-PR	450.0 kg	Normal Operations 384.0 W Stand-by 200.0 W Survival 350.0 W	± 8 W
Ka-PR	330.0 kg	Normal Operations 326.0 W Stand-by 150.0 W Survival 350.0 W	± 8 W
GMI	124.0 kg	Normal Operations 155.0 W Stand-by 100.0 W Survival 48.0 W	± 5 W
Total	904.0 kg	Normal Operations 960.0 W Stand-by 450.0 W Survival 748.0 W	

- ***4.6.2 (Instrument) Anomalous Condition Commanding***
  - *Execution of preplanned commands in response to anomalous conditions, or in response to entering any contingency state.*

Instrument Suite Data Rate Allocations

- **4.6.4 Instrument Suite Data Rate Allocations**

Instrument Data Rates	Science (Kbps)	Housekeeping (Kbps)	Allocation (Kbps)
KuPR	108.5	1	192
KaPR	81.5	1	
GMI	34	1	35
Total	224.0	3	227

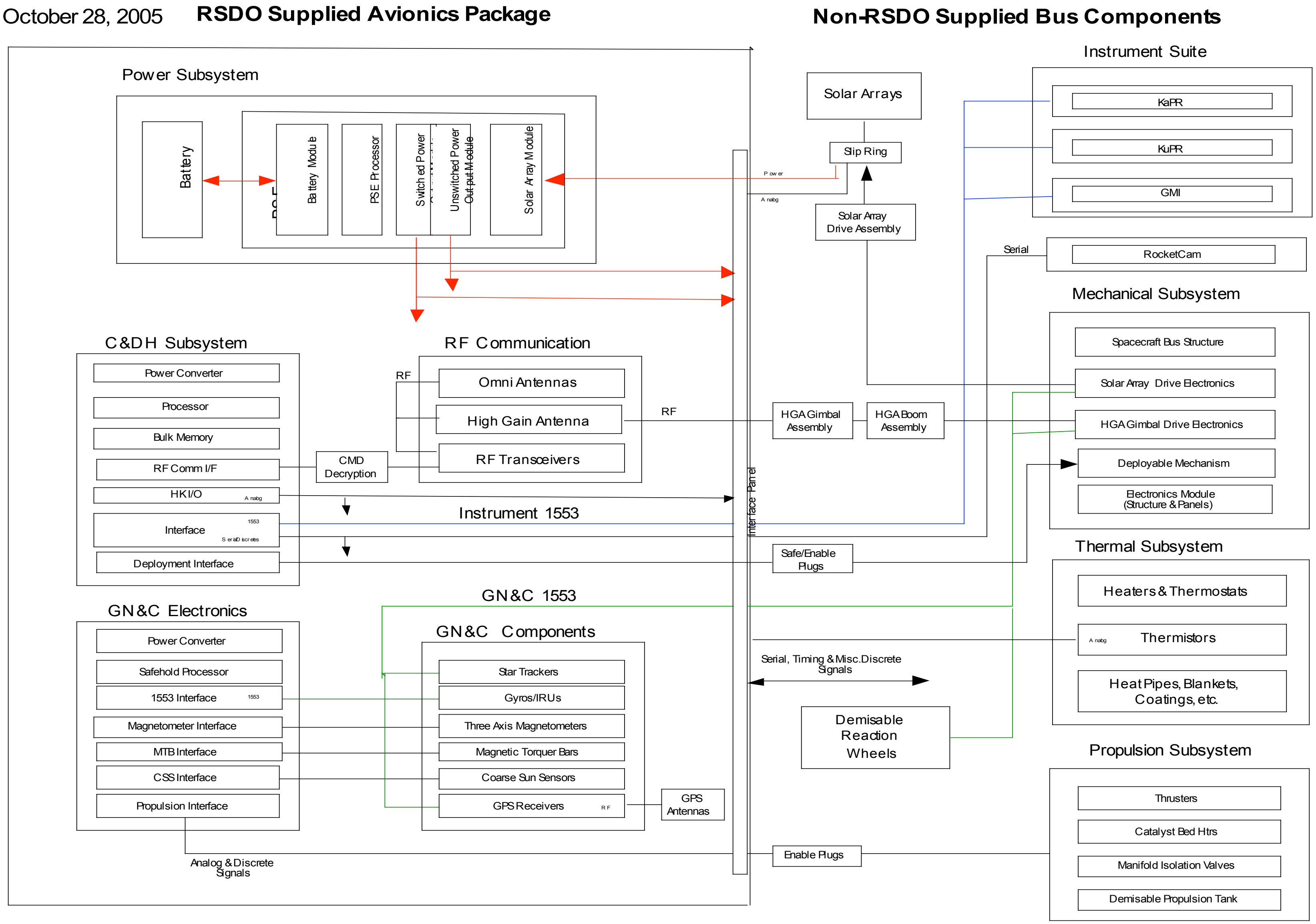
4.6.1.1 Dual redundant MIL-STD-1553 data busses

Spacecraft Subsystem Requirements

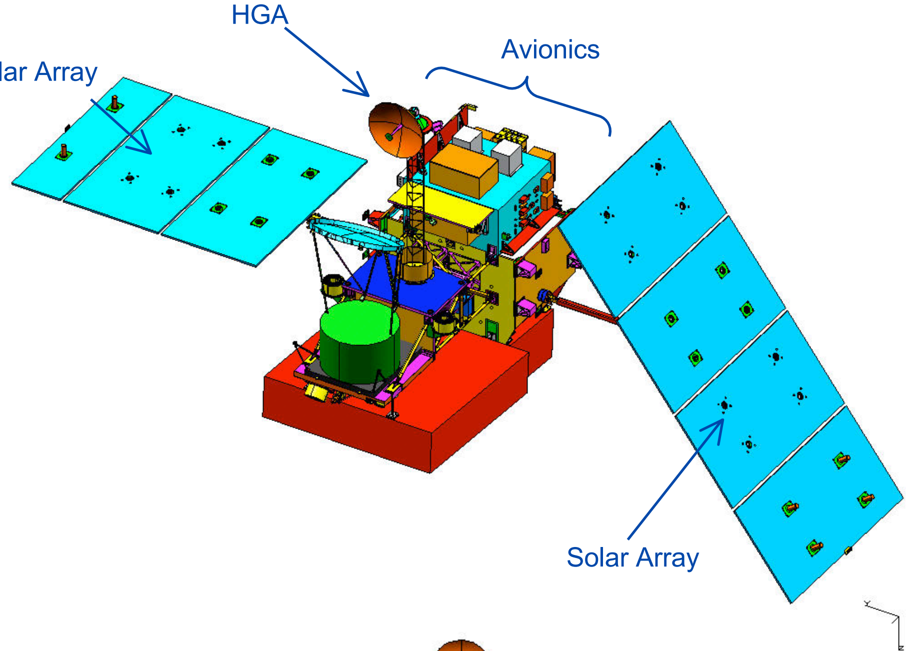
Notional GPM Hybrid System Block Diagram

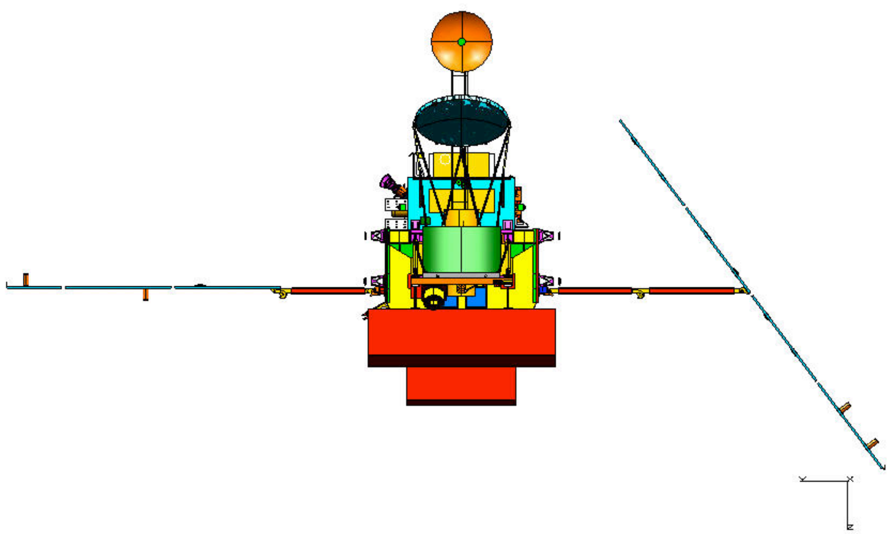
Revision 1.8.2

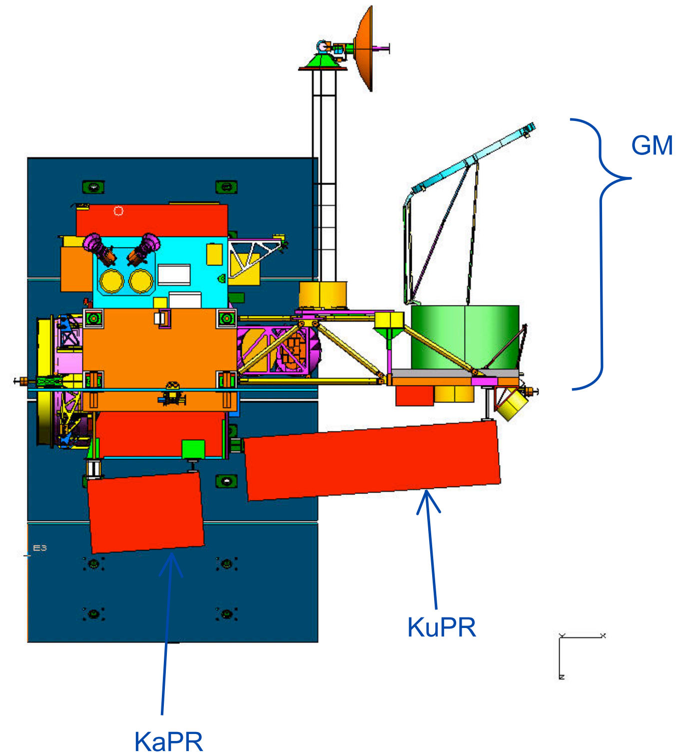
October 28, 2005



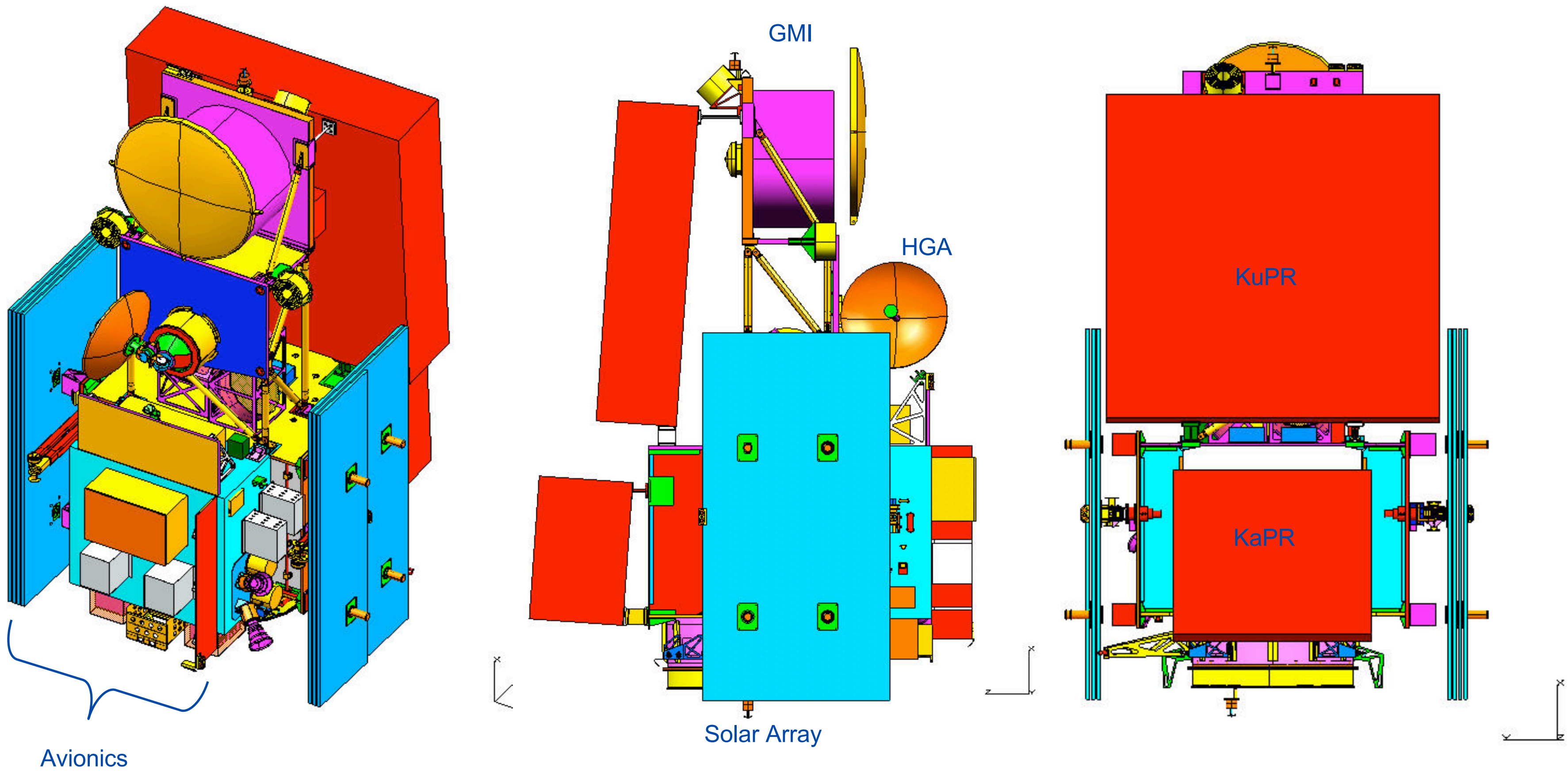
Spacecraft Deployed



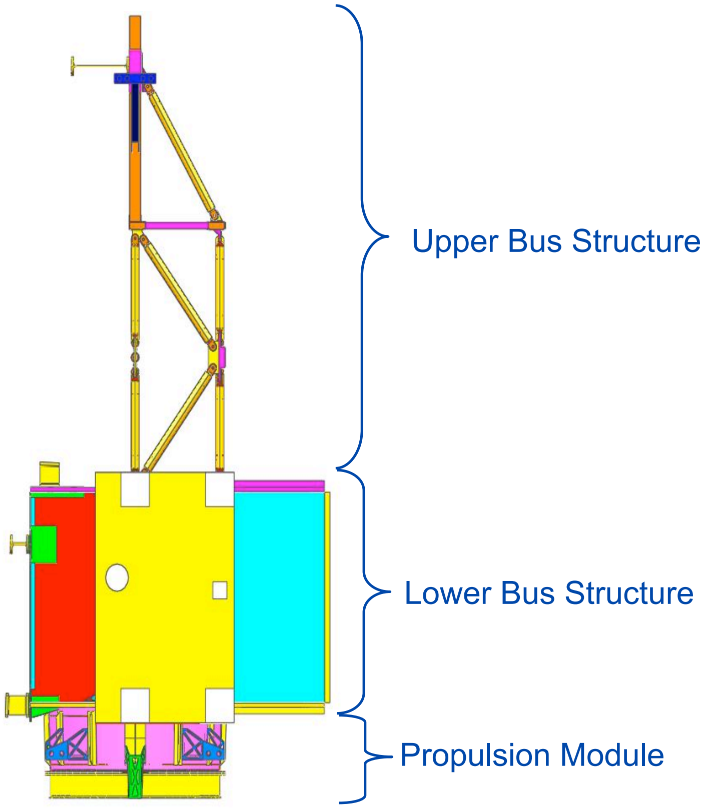


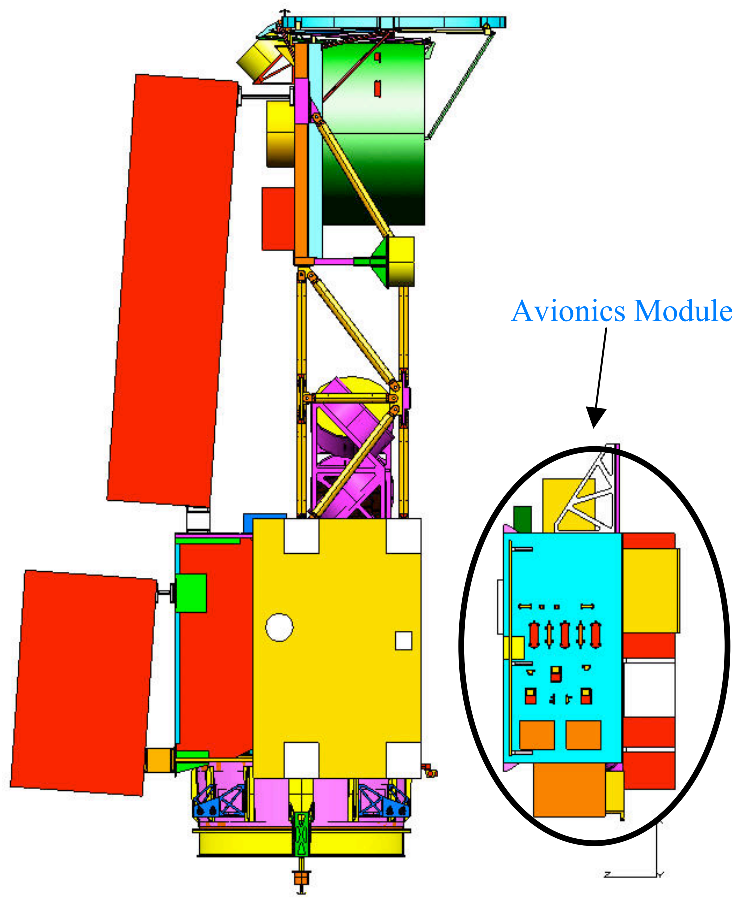


Spacecraft Stowed

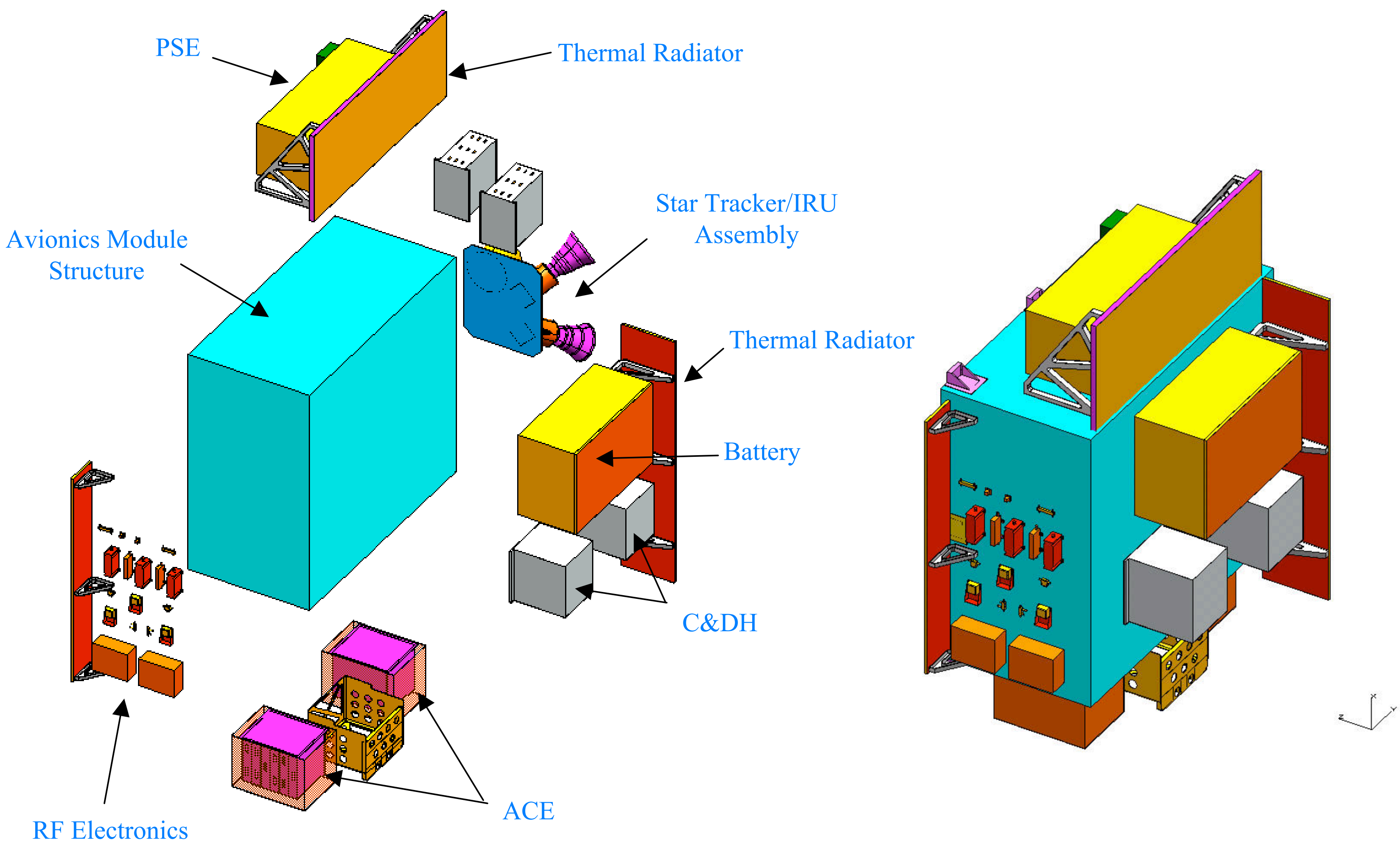


Spacecraft Nomenclature





Avionics Module – Exploded View



Observatory Mass Allocations

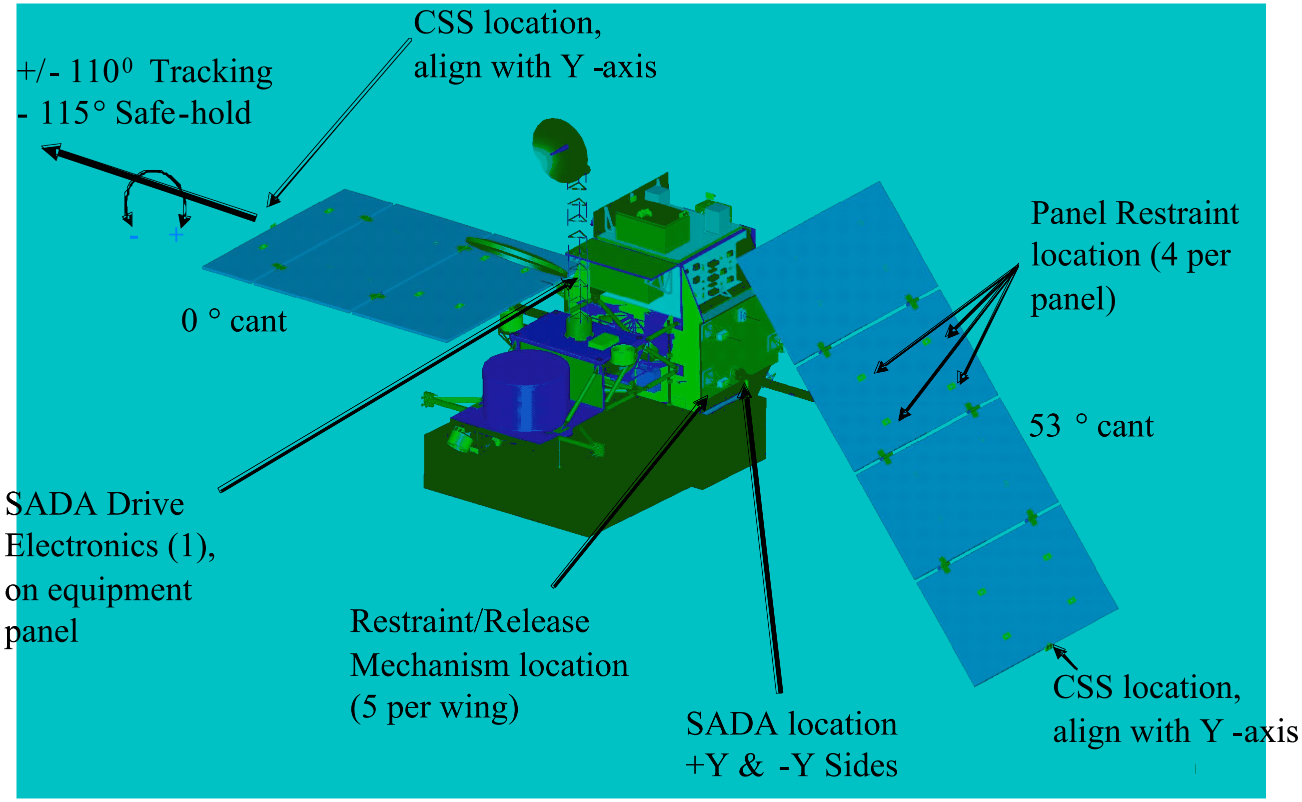
- ***5.1.1.1 Spacecraft Instrument and Component Mass Allocations - Preliminary***

	Allocation (kg)
Instruments Total	905.0
Avionics Package	380.0
Non-Avionics Package (GSFC)	1126.9

- ***5.1 Structural/ Mechanical Requirements***
- *5.1.2 Frequency Requirements*
- *5.1.3 Design Factors of Safety*
- *5.1.4 Static Loads*
- *5.1.5 Acoustic*
- *5.1.6 Random Vibration*
- *5.1.7 Swept Sine Vibration*
- *5.1.8 Shock*
- *5.1.9 Pressure*

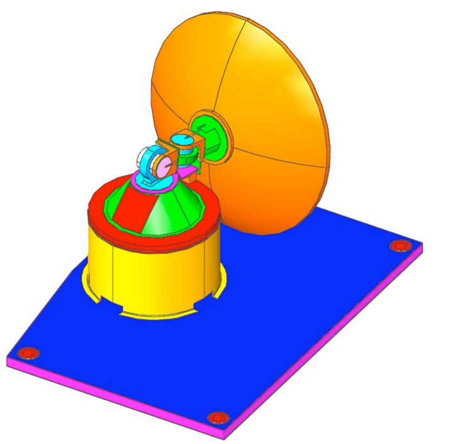
- ***5.1.12 Mechanisms / Deployables Design Requirements***
  - *5.1.12.1 Fault Tolerance of Deployables*
  - *5.1.12.2 Torque and Force Margin*
  - *5.1.12.3 Solar Array Deployment Tip-Off Design Rates*
  - *5.1.12.4 Deployment Inhibits*

- ***Solar Array Deployment and Drive System***

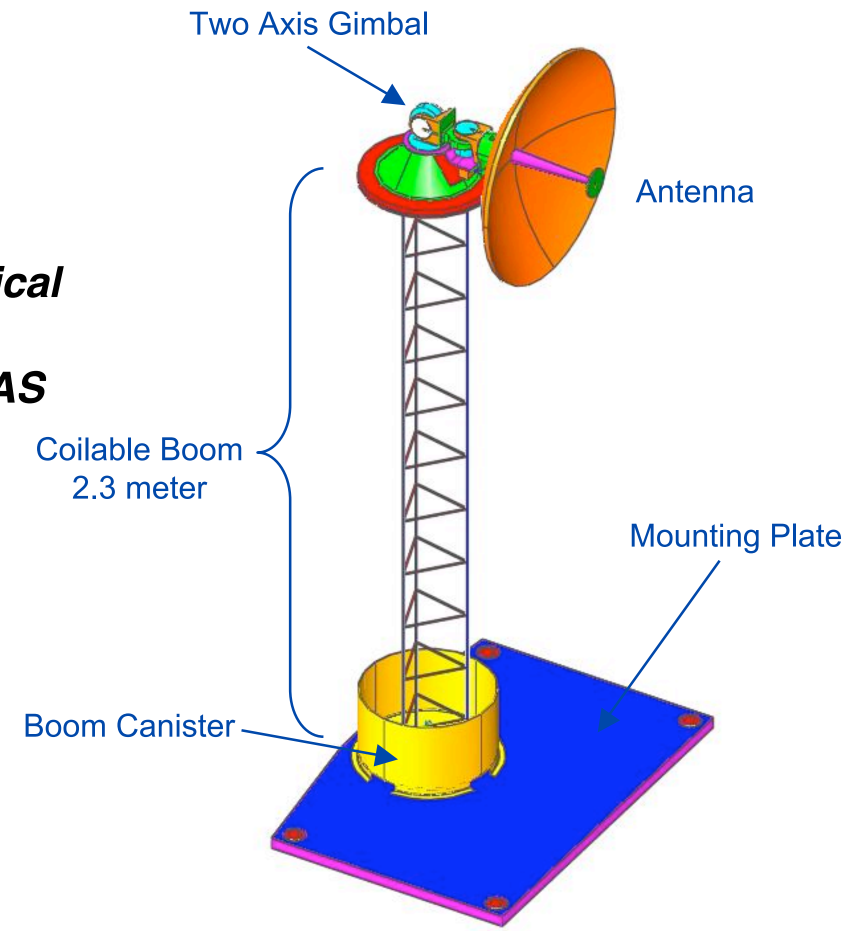


Mechanisms/Deployables

- ***High Gain Antenna System***
- ***Mechanical Redundancy planned for all release actuators***
  - *2 actuators at Gimbal launch lock*
  - *2 actuators at boom canister release mechanism*
- ***2-axis Gimbal will provide HGA with spherical coverage***
- ***Gimbal Control Electronics located on HGAS Mounting Plate***



Stowed Configuration



Deployed Configuration

Observatory Power

- ***5.2.1 Observatory Requirements***
  - *Maximum Load Capability ≤ 1950W*

- ***5.2.2 Spacecraft Power Allocation - Preliminary***

Power Allocation	Orbital Average (W)
Instruments	960 W
Avionics Package	600 W
Non-Avionics Package (GSFC)	250 W
Spacecraft Total	1810 W

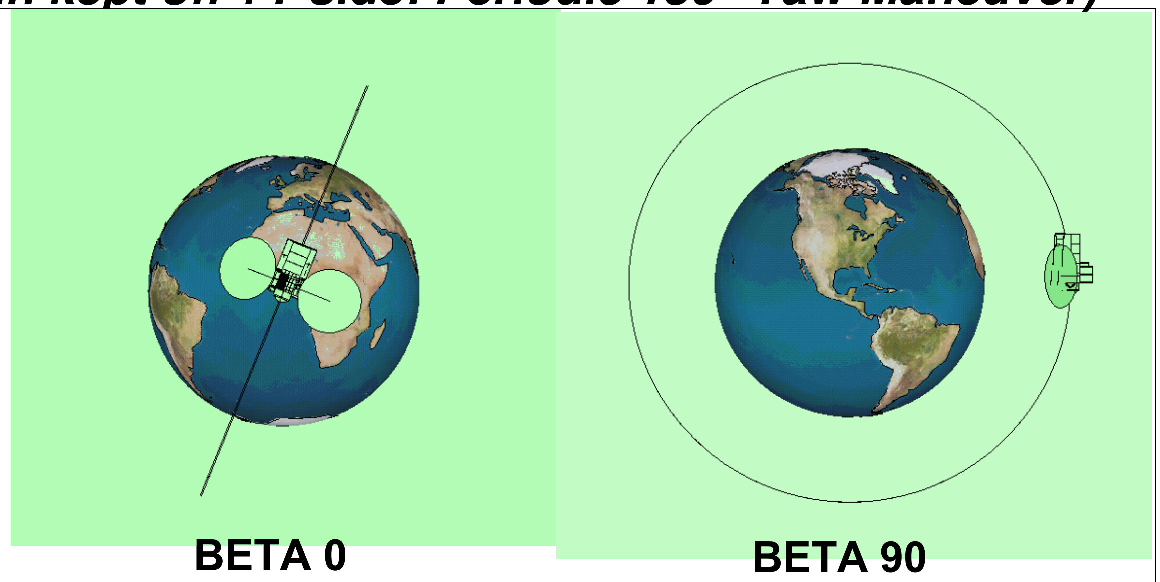
Observatory Electrical

- **5.2.6 Operational and Survival Voltage Requirement**
  - Operational voltage is 29 ± 6 Vdc unregulated power.
  - Subsystems and components to survive input voltages from 0 to 40 Vdc
- **5.2.4 Power Management**
  - Fault detection, clearance, and load shedding
- **5.2.7 Over-voltage Protection**
- **5.2.8 In-Rush Current Circuit Protection**
- **5.2.9 Grounding**
  - Preliminary grounding scheme in supplemental slides
- **5.2.10 Pyrotechnic Isolation**

Observatory Thermal Control Requirements

- **5.3.1 Thermal Control Subsystem Requirements:**
  - *Maintain acceptable temperatures of all spacecraft components for all mission modes*

(Sun kept off +Y side: Periodic 180° Yaw Maneuver)



ORBIT SOLAR BETA ANGLE EXTREMES
SUN VIEWS

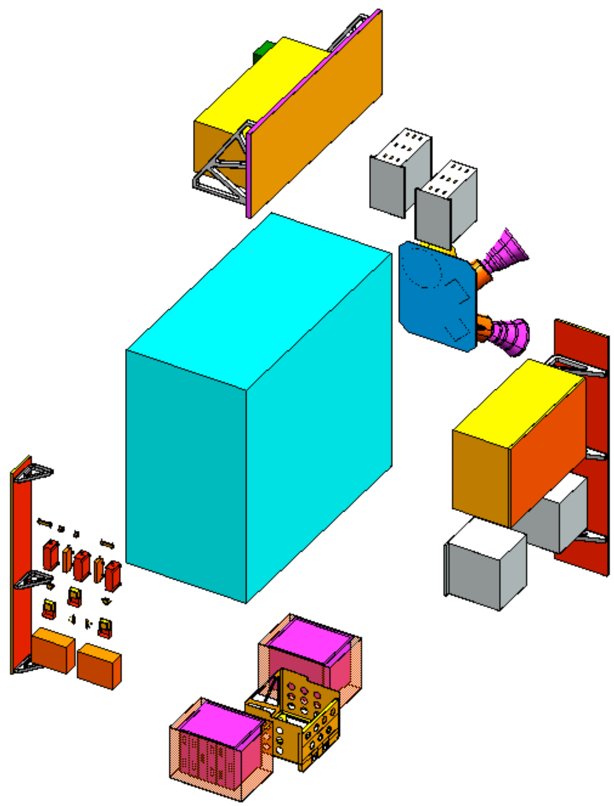
- **5.3.2 Thermal Design Margin**
  - *Operating Limits, ± 10° C*

Spacecraft Propellant Requirements

- ***5.4.1 Propellant Requirements***
  - ***5.4.1.1 Propellant Allocation Budget***

Mission Delta-V Summary	Delta-V (m/s)	Propellant (kg)
Orbit Insertion	70	102
Orbit Maintenance	161	233
Attitude Control	45	64
De-Orbit	0	0
Total Delta V Required	276 m/s	
Unusable Propellant		11
Total Propellant Required		400
Propellant Load		480
Margin		20%

- ***5.5.1 Functional Requirement***
  - *Meet all functional requirements of the incorporated subsystems: Power and Electrical ,GNC, Communications, C&DH, and FSW*



Avionics Package Allocations:

Mass: 380 kg

Power: 625 Watts, Orbital Average

Data Rate: 10 kbps, S/C HSK

5.5.1.1.2 Maximum Solar Array Load Sizing
5.5.1.1.3 AP Power Subsystem Interface
5.5.1.1.4 Electrical Harness Design and Fabrication

•5.5.1.2.1 Observatory Pointing, Stability and Control Requirements

Characteristic Requirement	Mission Precision Pointing	Engineering Coarse Pointing	Acquisition/ Contingency Pointing
Knowledge (Resolution)	± 0.10° (3_)	± 0.10° (3_)	± 3.0° (3_)
Accuracy (Control)	± 0.20° (3_)	± 3.00° (3_)	± 10.0° (3_)
Stability (peak-to-peak over one second)	± 0.01°/sec (3_)	± 0.10°/sec (3_)	n/a

Maneuvers

5.5.1.2.2 Orbit Adjust Maneuvering

5.5.1.2.3 180° Yaw Maneuvering

5.5.1.2.4 90° Yaw Maneuvering

AP: Communications Requirements

- ***5.5.1.3.1 General Requirements***
  - *TDRSS S-Band forward and return communications link services for primary communications capabilities*
    - *TDRSS-SA service for nominal mission operations*
    - *TDRSS-MA service for real-time services*
  - *Ground Network (GN) communications link services for:*
    - *Back-up communications during launch and deployment activities until TDRSS capture is attained.*
    - *Back-up data transmission, command reception, and mission support as a result of TDRSS unavailability.*

•5.5.1.3.6 Uplink and Downlink Data Rates

Communications Link	Data Rate	Margin	Modulation	Purpose/Antenna
TDRSS-MA				**Real-time Data Link**
Forward	64 kbps	3 db	SS-BPSK	HGA
Forward	350 bps	3 db	SS-BPSK	Omni (Contingency)
Return	4 kbps	3 db	SQPN	Omni (Contingency)
	230 kbps	3 db	SQPN	HGA
TDRSS-SA				**Data Recovery Link**
Forward	2 kbps	3 db	SS-BPSK	Omni (Contingency)
	2 kbps	3 db	SS-BPSK	HGA (Contingency)
	64 kbps	3 db	SS-BPSK	HGA
Return	4 kbps	3 db	SQPN	Omni (Contingency)
	2.3 Mbps	3 db	SQPSK	HGA
Ground Network				**Back-Up Operations**
Forward	2 kbps	3 db	BPSK	Omni (Contingency)
	64 kbps	3 db	BPSK	Omni-directional
Return	4 kbps	3 db	SQPSK	Omni (Contingency)
	4 Mbps	3 db	SQPSK	Omni-directional

AP: Antenna Designation, RF Frequency, Quality

- ***5.5.1.3.3 S-Band Antenna Requirements***
  - *Deployable high gain antenna (HGA) for primary S-Band communications to the TDRSS system*
  - *Omni-directional antennas (omni) for primary S-band communications to the TDRSS system prior to deployment of the high gain antenna, and for contingency communications to the TDRSS system and Ground Networks*
- ***5.5.1.3.4 Uplink and Downlink Frequencies***
  - *2287.5 MHz (TDRSS-MA Return)*
  - *2287.5 MHz (TDRSS-SA Return)*
  - *2106.4 MHz (forward)*
- ***5.5.1.3.8 End-to-end Minimum Bit-Error-Rate (BER)***
  - *10-7 for the SN return links*
  - *10-5 for the GN return links*
- ***5.5.1.3.10 Return Link Frame Structure***
- ***5.5.1.3.11 Forward Link Frame Structure***
  - *CCSDS Compliant*

GLOBAL PRECIPITATION MEASUREMENT

- ***5.5.1.3.2 Data Latency Requirements***
  - *All mission data within one orbit of observation*

- ***5.5.1.4.1.1 Data Processing Requirements***
  - *Data Rate, Collection, Transmission and Storage*
    - *5.5.1.4.1.3 Storage of no less than twelve (12) hours of science and housekeeping data without loss*

- ***5.5.1.4.1.7 Command Encryption***
  - *S/C to decrypt the NIST-approved protocol encrypted command up-link*

- ***5.5.1.5 Spacecraft Timing Reference and Adjustment Requirements***
  - *Reference spacecraft time to 1 millisecond minimum, relative to Universal Time Coordinated (UTC)*
  - *Incorporate spacecraft time update adjustment capabilities from ground command or autonomously from the Global Positioning Satellite (GPS) system when enabled*

AP: Flight Software Applications

- ***5.5.1.6.4 Software Applications***
  - *The GPM Core Spacecraft shall support the following software applications:*
    - *5.5.1.6.5 Science Data Processing*
    - *5.5.1.6.6.Spacecraft Fault Processing*
    - *5.5.1.6.6.1 Power Management*
    - *5.5.1.6.7 Autonomous Operation*
    - *5.5.1.6.7.1 High Gain Antenna System (HGAS) Pointing*
    - *5.5.1.6.7.2 Solar Array Drive and Deployment System (SADDS) Pointing*
    - *5.5.1.6.7.3 Ephemeris Derivation and Propagation Requirements*
    - *5.5.1.6.7.5 Autonomous File Management*
    - *5.5.1.6.7.4 Autonomous TDRSS Demand Access Service (DAS) Scheduling*
    - *5.5.1.6.8 GN&C Sensor/Actuator Polarity Correction*
    - *5.5.1.7.5 Memory Dwell*
    - *5.5.1.7.6 Memory Validation*
    - *5.5.1.7.7 Event Log*
    - *5.5.1.7.8 Pre-Launch High Speed Processor Load Capability*
    - *5.5.1.7.9 Software Load Segment Capability*
    - *5.5.1.7.11 Command Parser Capability*
    - *5.5.1.7.12 Ancillary Data Instrument Broadcast*

GLOBAL PRECIPITATION MEASUREMENT

5.5.1.7.10 On-Board Processor Resource Margins

– *Processors that provide computing resources for spacecraft subsystems shall be sized such that, in the normal Spacecraft operating modes, the margins (measured as a percentage of the total available resource) are maintained at launch:*
  - *a) 30 % of the CPU utilization capacity (throughput)*
  - *b) 30 % of the Random Access Memory (RAM) capacity*
  - *c) 30 % of the EEPROM capacity*
  - *d) 10 % of the instrument data bus utilization capacity*

- **6.0 Space Environmental Requirements**
  - The GPM Core Spacecraft shall be capable of nominal operations under natural and induced environmental conditions for the mission orbit. These environmental conditions include, but are not limited to the following:
    - Atmospheric Pressure (Vacuum)
    - Magnetics
    - Meteoroids (micro-meteoroids)
    - Orbital Debris
    - Radiation
    - Atomic Oxygen
    - Electromagnetic Interference (EMI)/ Electromagnetic Compatibility (EMC)

Electrical Ground Support Equipment

- **7.2 Core Spacecraft Electrical Ground Support Equipment**
  - 7.2.1 Core Spacecraft Interface Simulator (SIS)
    - Verify electrical interface before instrument delivery to the Spacecraft
  - 7.2.2 High Fidelity Flight Software Test Bench
    - Flight software systems testing
    - Training of GPM Flight Operations Team (FOT)
    - Flight software maintenance during final integration and test operations and on-orbit operations
  - 7.2.3 Core Spacecraft Command and Telemetry Simulator
    - Used as a tool to develop and test Ground System software used by the GPM Flight Operations Team

- ***Supplemental Slides***
  - *Requirements Traceability Matrix*
  - *GPM Core Spacecraft Mass Estimate*
  - *GPM Core Spacecraft Power Estimate*
  - *Design-for-Demise Allocations*
  - *Safe Hold Mode Requirements*
  - *Geo-Location Preliminary Budget Allocations*
  - *DPR Co-Alignment Preliminary Budget Allocations*
  - *Thermal Radiators*
  - *Thermal Heat Pipes*
  - *Thermal MLI, Other*
  - *AP Harness Design Requirements*
  - *GPM Core Spacecraft Master Interconnect Harness Diagram*
  - *Spacecraft Grounding Scheme*
  - *Spacecraft Grounding Diagram*
  - *AP Integration*
  - *GPM Core Spacecraft Integration and Test Flow*

Requirements Traceability Matrix

	Level 2 Requirement		Level 3 Requiremnent
2.0	NASA Programmatic and Technical Requirements	2.0	Applicable/Referenced Documents
		2.1	Applicable Documents
2.1	GPM Specific Tailoring of Programmatic/Technical Requirements	2.1.1	GPM Specific Tailoring of Programmatic/Technical Requirements
2.1.1	NPD 8010.2C Use of the Metric System of Measurement in NASA Programs	2.1.1.1	NPD 8010.2C :Use of the Metric System of Measurement in NASA Programs
2.2.1	Launch Readiness Date – Core Observatory	3.2.1	Observatory Launch Readiness Date
2.2.5	Mission Assurance Requirements	3.5	Mission Assurance Requirements
		3.6	Redundancy, Fault Tolerance and Safety Design Requirements
		3.6.1	Mission Failure - Single Fault Tolerance Design Requirements
		3.6.2	Safety Design Requirements
		3.6.2.1	Safety Failure-Tolerance Design Requirements
		3.6.2.2	Control of Hazardous Functions
		3.6.2.3	Design for Minimum Risk
		3.6.2.4	Industrial Safety Requirements
		3.7	GPM Core Spacecraft Reliability Design Requirements
		3.7.1	GPM Core Spacecraft Subsystem Reliability Design Requirements
2.2.6	End-of-Life Reentry Requirements	3.2.4	Observatory Decommissioning
		3.2.4.1	End-of-Life Disposal

Requirements Traceability Matrix

		3.2.4.1.1	Design-for-Demise
		3.2.4.1.2	Design-for-Demise Debris Casualty Area
		3.2.4.1.3	Design-for-Demise Debris Casualty Area Allocations
2.2.7	Use of Metric Units	2.1.1.1	NPD 8010.2C :Use of the Metric System of Measurement in NASA Programs
2.2.8	Use of CCSDS Standards	5.5.1.3.10	Return Link Frame Structure
		5.5.1.3.11	Forward Link Frame Structure
2.2.9	Science Data File Transmission	5.5.1.3.12	GPM shall implement the CCSDS File Delivery Protocol (CFDP) controlling space-ground file transmissions.
2.2.10	Data Collection Completeness	5.5.1.4.1.4	Data Loss Requirement
2.2.11	Data Collection Efficiency	3.4.3	Engineering Mode
		3.4.4.2.1.2	Maximum Time for 90° Yaw Maneuver
		3.4.4.5	Mission Mode Availability
2.2.12	Space Asset Protection		
3.2.2	Data Latency	5.5.1.3.2	Data Latency Requirements
4.1.1	DPR Interface Requirements	4.1.1	ICD Requirements
4.1.8	DPR Data Rate Allocation	4.6.4	Instrument Suite Data Allocation
4.1.9	(DPR) Calibration	3.4.4.2	Instrument Test and Calibration Sub-Mode
		3.4.4.2.1	90° Yaw Maneuver Sub-Mode

4.2.2	GMI Interface Requirements	4.1.1	ICD Requirements
4.2.10	GMI Data Allocation	4.6.4	Instrument Suite Data Allocation
5.0	GPM Core Observatory Requirements	3.0	Core Spacecraft Design Requirements
5.1	Core Observatory Initial Operational Capability	3.2.1	Observatory Launch Readiness Date
5.2	Core Observatory On-orbit Checkout	3.2.2	Observatory Commissioning Phase
		3.4	Observatory Mission States
		3.4.2	Initial Orbit Acquisition State
		3.4.2.1	Initial Acquisition Time
		3.4.3	Engineering Mode
5.3	Core Observatory Lifetime	3.2	Core Spacecraft Lifetime Requirements
		3.2.1	Observatory Launch Readiness Date
		3.2.2	Observatory Commissioning Phase
		3.2.3	Operational Phase
		3.2.3.1	Sizing for Consumables
		3.2.4	Observatory Decommissioning
5.4	Core Spacecraft Reliability	3.7	GPM Core Spacecraft Reliability Design Requirements
		3.7.1	GPM Core Spacecraft Subsystem Reliability Design Requirements
5.5	Core Observatory Nominal Operating Orbit	3.1	Core Spacecraft Orbit Definition and Attitude Reference Frames
		3.1.1	Core Spacecraft Orbit Definition
		3.3.1	Launch Vehicle Interface Requirements
		3.3.2	Injection Orbit
5.6	Core Observatory Nominal Inclination	3.1	Core Spacecraft Orbit Definition and Attitude Reference Frames
		3.1.1	Core Spacecraft Orbit Definition

Requirements Traceability Matrix

5.7	Core Observatory Launch Vehicle Capability	3.3.3	Launch Vehicle Mass Allocation
5.8	Autonomy of Core Observatory – Science Operations	3.4.4	Mission Mode
		3.4.4.1	Mission Mode Autonomous Operation
		3.8.1	TDRSS Temporary Unavailability
5.9	Core Observatory Safe Hold Mode	3.4	Observatory Modes of Operation
		3.4.5	Safe Hold Mode
		3.4.5.1	Safe Hold Mode Characteristics
		3.4.5.2	Primary Observatory Attitude - Safe Hold Mode
		3.4.5.3	Primary Communications Links - Safe Hold Mode
5.10	Core Observatory Instrument Accommodation	4.0	Instrument Complement Support Requirements
5.10.1	On-board orbit/time information	5.5.1.6.5.2	Instrument Science File Content Requirements
5.10.2	GPM Core Observatory Instrument Complement	4.0	Instrument Complement Support Requirements
		4.1.1	ICD Requirements
		5.1.10	Instrument Accommodations
5.10.3	S/C Nominal Nadir Pointing Control	3.1	Core Spacecraft Orbit Definition and Attitude Reference Frames
		3.1.2	Core Spacecraft Attitude Reference Frame
		3.1.2.1	Nominal Core Spacecraft Orientation
		3.3.5	Launch Vehicle Tip-Off Rate Design Capability

		3.4.3	Engineering Mode
		3.4.3.1	Observatory Orientation - Engineering Mode
		3.4.4	Mission Mode
		3.4.4.2.1.1	Observatory Attitude - 90° Yaw Maneuver
		3.4.4.3	Observatory Orientation - Mission Mode
		3.4.5.2	Primary Observatory Attitude - Safe Hold Mode
5.10.4	Geolocation of GMI Measurements	4.2	Geo-Location and Co-Alignment of Instrument Science Measurements
		4.2.1	Geo-Location of Instrument Science Measurements
5.10.5	Geolocation of DPR Measurements	4.2	Geo-Location and Co-Alignment of Instrument Science Measurements
		4.2.1	Geo-Location of Instrument Science Measurements
5.10.6	Orientation and Clear Field-of View	4.0	Instrument Complement Support Requirements
		4.3.3	Instrument FOV Requirements
		3.4.4.3	Observatory Orientation - Mission Mode
		5.1.10	Instrument Accommodations
5.10.7	Power Interface	4.4	Instrument Suite Electrical Interface Requirements
		4.4.2	Instrument Suite Power Allocation and Operational Timeline

5.10.8	Thermal Interface	4.5	Instrument Suite Thermal Control Requirements
5.10.9	DPR Coalignment	4.2	Geo-Location and Co-Alignment of Instrument Science Measurements
		4.2.2	Co-Alignment of KuPR and KaPR Instrument Science Data
		4.2.2.1	Observatory Co-Alignment Budget Allocations
5.10.10	Data Rate	4.6.4	Instrument Suite Data Allocation
5.11	Communications	5.5.1.3	Communications Requirements
5.11.1	Downlink Capacity and Margin	5.5.1.3.2	Data Latency Requirements
		5.5.1.4.1.1	Data Rate, Collection, Transmission and Storage
		5.5.1.4.1.2	Spacecraft Data Rate Allocation
5.11.2	Downlink for Health and Safety	5.5.1.3.2	Data Latency Requirements
		5.5.1.4.1.1	Data Rate, Collection, Transmission and Storage
		5.5.1.4.1.2	Spacecraft Data Rate Allocation
		5.5.1.4.1.3	Data Storage Requirement
5.11.3	Core Observatory Communications	5.5.1.3	Communications Requirements
5.11.3.1	Primary Communication Links	5.5.1.3.1	General Requirements
		3.4.3.2	Communications Links - Engineering Mode
		3.4.4.4	Communications Links - Mission Mode
		3.4.5.3	Primary Communications Links - Safe Hold Mode
5.11.3.2	Backup Communication Links	5.5.1.3.1	General Requirements
		3.8.2	Failure of TDRSS High-Gain Antenna

Requirements Traceability Matrix

5.11.3.3	Data Storage for Core Spacecraft	5.5.1.4.1.3	Data Storage Requirement
5.12	Core Observatory Launch Vehicle Requirements	3.3	Launch System Requirements
5.12.2	Core Observatory Launch Vehicle Compatibility	3.3	Launch System Requirements
		3.3.1	Launch Vehicle Interface Requirements
		3.3.4	Launch Configuration Stowed Frequency
		3.3.5	Launch Vehicle Tip-Off Rate Design Capability
		3.4.1	Launch Mode
		5.1.11	Launch Vehicle Accommodations
5.12.3	Core S/C Launch Site Processing		

GPM Core Spacecraft Mass Estimate

- *Instrument Mass includes increases due to GMI High Frequency Channels and new mounting deck*
- *Propellant mass based on full tanks not mission requirement*
- *Golden Rules Requirement of 20% Margin During Phase B is Satisfied*

Mission Mass (kg)	**11/21 Current Best Estimate (kg)**	**11/21/05 Allocation (kg)**
Instruments		
KuPR	427.9	450.0
KaPR	316.4	330.0
GPM Microwave Imager	110.8	125.0
Instrument Total	**855.1**	**905.0**
RSDO Supplied Avionics Components:		
GN&C (w/out reaction wheels)	68.7	
C&DH	32.5	
Power Total (sum of next 2 lines)	129.0	
Battery	70.0	
Power System Electronics	59.0	
RF Communications	14.6	
HGAS - Antenna & RF Harness	13.48	
Electrical Harness	90	
RSDO Total	**348.3**	**380.0**
GSFC Supplied Spacecraft Bus Subsystems and Structure:		
GN&C		
Reaction Wheels	59.2	65.0
C&DH	0.0	0.0
Power Total (sum of next 3 lines)	208.3	215.3
Battery	0.0	0.0
Power System Electronics	0.0	0.0
Solar Panels/ SADA	208.3	215.3
Thermal	73.1	90.3
RF Communications	0.0	0.0
HGAS - Gimbal & Boom	30.1	44.3
Propulsion (Dry Mass) - 1 Side Thruster Config	84.2	102.0
Electrical Harness	90.0	90.0
Structure	379.0	520.0
GSFC Bus Subsystems Total	**923.9**	**1126.9**
Dry Mass Total (Instrument+RSDO+GSFC)	**2127.3**	**2411.9**
Propulsion		
Pressurant	9.5	9.5
Unusable Propellant	10.0	11.0
EOL Mass	**2146.8**	**2432.4**
Propellant	**480.0**	**480.0**
BOL Mass (Launch)	**2626.8**	**2912.4**
Observatory Reserve	573.2	287.6
Launch Mass	**3200.0**	**3200.0**
Launch Mass minus Prop Mass	2720.0	2720.0
Margin (% of Dry Mass)	**27.9%**	**12.8%**

GPM Core Spacecraft Power Estimate

GPM Power Allocations and Estimate

Last update: November 30, 2005

Instruments	Estimate (Watts)	Allocations (Watts)	Rationale
KuPR	367	384	
KaPR	310	326	
GMI	122	155	
		95	System Reserve
Instrument Total	**799**	**960**	Total Inst. Alloc.
Instrument Margin	161		
Instrument Margin %	20.15%		
RSDO Supplied Components			
GN&C	190	152	200-4xrwa
C&DH	98	109	
PSE	96	96	
Thermal	91	108	194-86
RF/Comm	67	103	
		32	Reserve
RSDO Total	**542**	**600**	AP Allocation
GSFC Supplied Components			
HGAS	52	57	
SADS	44	48	
RWA	48	52	
Thermal (Propulsion)	86	93	
GSFC Total	**230**	**250**	GSFC Allocation
Spacecraft Total	772	850	
Observatory Total	**1571**	**1810**	
Observatory Capability		1950	
Observatory Margin	379	140	
Observatory Margin %	**24.12%**		

Power Requirements to RSDO Vendor:

1. Instrument Power Allocation = 960 W
2. Obervatory Overall Power Margin to Meet GSFC Rules of 20% @PDR
3. Solar Array Constraints - Panel size = 9.5 m^2 +y/ 13.4 m^2 -y
4. Orbit at 407 Km / 65 deg
5. End of Life power requirements

3.2.4.1.3 Design-for-Demise Debris Casualty Area Allocations

Observatory Element	DCA Allocation
Instruments	
GMI	2.00 m_
KuPR	0.00 m_
KaPR	0.00 m_
Spacecraft Subsystems	0.00 m_
RWAs	0.00 m_
Propellant Tank	0.00 m_
SADDA	1.10 m_
HGA Gimbals	1.30 m_
Structures	0.00 m_
Observatory Total	**4.40 m_**
Margin	3.60 m_
Requirement	**8.00 m_**

– **3.4.5 Safe Hold Mode**

- *In the event of the detection of an anomalous condition that threatens the health and safety of the observatory, the GPM Core Spacecraft shall automatically enter a spacecraft contingency state, without the direct involvement of either the ground segment or the ground operations personnel, and acquire/maintain attitude orientations commensurate with the anomaly*
  - *Science collection activities cease*
  - *A series of planned, staged activities (as deemed necessary) shall remove power from the instruments and "non-essential" subsystems*
  - *The primary attitude of the GPM Core Spacecraft shall be a the nominal nadir pointing orientation unless the nature and severity of the condition warrant a solar pointing orientation*
  - *Primary communications to the GPM Core Spacecraft shall be through the low gain antenna, utilizing the TDRSS-SA service for telemetry receipt and for commanding*

– **3.4.5.1 Safe Hold Mode Characteristics**

- *The Spacecraft Safe Hold Mode shall have the following characteristics*
- *1) Its safety shall not be compromised by the same fault that led to Safe Hold activation*
- *2) It shall be as simple as practical, employing the minimum hardware set required to maintain a safe attitude.*
- *3) It shall have the capability to remain in Safe Hold for up to 168 hours without ground intervention*
- *4) It shall have the capability to remain in Safe Hold indefinitely with ground intervention.*

– **3.4.5.2 Primary Observatory Attitude – Safe Hold Mode**

- *The primary attitude of the GPM Core Spacecraft shall be the defined nadir pointing orientation unless the nature and severity of the condition warrant the defined solar pointing orientation. Maintenance of the safe hold attitude control requirements shall be as specified in section 5.5.1.1.1, is required*

– **3.4.5.3 Primary Communications Links – Safe Hold Mode**

- *Primary communications to the GPM Core Spacecraft during Safe Hold Mode shall be through the low gain antenna, utilizing the TDRSS-SA service and Ground Network (GN) for telemetry receipt and for commanding*

• 4.2.1.1 Geo-Location Budget - Preliminary

DPR GEOLOCATION KNOWLEDGE (arc-min)

ERROR SOURCE	RX (ROLL) CROSSTRACK	RY (PITCH) ALONGTRACK	RY DUE TO RZ	RZ (YAW)
RANDOM ERRORS:				
A. S/C CONTRIBUTIONS (between KuPR or KaPR and ACS Reference Cubes):				
THERMAL DISTORTION				
LAUNCH SHIFT				
MEASUREMENT ACCURACY				
OBSERVAORY JITTER				
ANALYTICAL UNCERTAINTIES				
SC TIMING ERROR				
RSS TOTAL S/C CONTRIBUTION	**3.000**	**3.000**		**3.000**
B. KuPR or KaPR INSTRUMENT INTERNAL :				
THERMAL DISTORTION				
LAUNCH SHIFT				
MECHANICAL ERROR/MEASUREMENT ACCURACY				
PHASE ERROR				
ANALYTICAL UNCERTAINTIES				
RSS TOTAL KuPR INSTRUMENT INTERNAL	**8.000**	**10.000**		**7.000**
C **ACS KNOWLEDGE**	**6.000**	**6.000**		**6.000**
T1 RSS of Random Errors	**10.440**	**12.042**		
BIAS ERRORS:				
SPACECRAFT GRAVITY RELEASE	0.000	0.000		0.000
SPACECRAFT MOISTURE DESORPTION	0.000	0.000		0.000
PLACEMENT BIAS of KaPR or KuPR onto SPACECRAFT	0.000	0.000		0.000
TOTAL SPACECRAFT BIAS:	**0.000**	**0.000**		**0.000**
INSTRUMENT GRAVITY RELEASE (KuPR OR KaPR):	0.000	0.000		0.000
INSTRUMENT MECHANICAL ERROR (KuPR OR KaPR):	0.000	0.000		0.000
INSTRUMENT MOISTURE DESORPTION (KuPR OR KaPR):	0.000	0.000		0.000
TOTAL INSTRUMENT BIAS:	**0.000**	**0.000**		**0.000**
T2 Sum of Bias Errors:	**0.000**	**0.000**		
TOTALS FROM ABOVE:				
T1 RSS of Random Errors	10.440	12.042		
T2 Sum of Bias Errors:	0.000	0.000		
T3 SUM OF RANDOM AND BIAS ERRORS	**10.440**	**12.042**		
RSS OF RX AND RY DIRECTIONS=	**15.937**			
REQUIREMENT (1/2 pixel, 2.5 km)	**21.116**			
MARGIN (arc-min)	**5.179**			

4.2.2.1 Co-Alignment Budget - Preliminary

DPR COALIGNMENT ERROR (allocation)

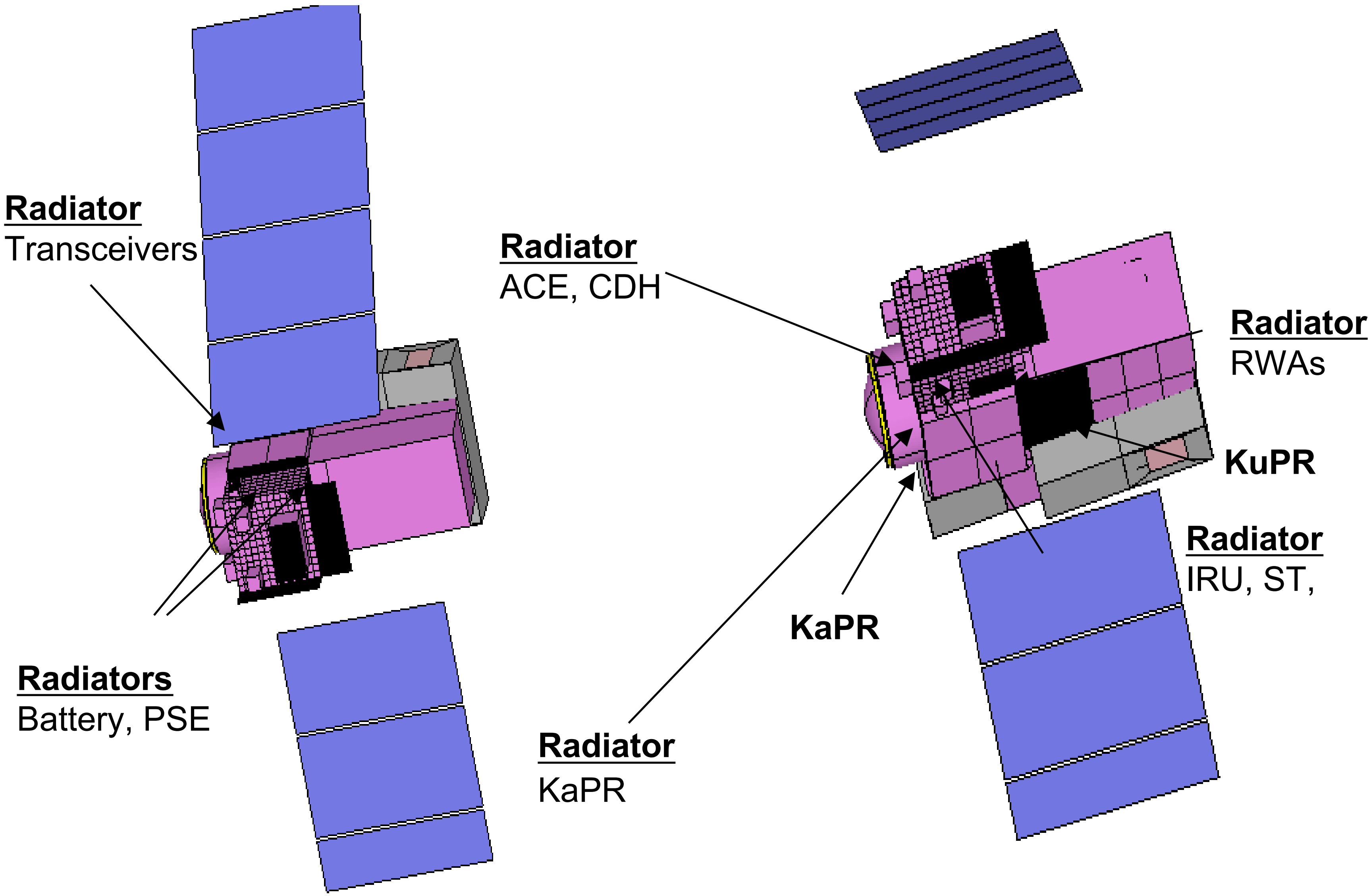
Post-Calibration/On-Orbit Co-Alignment (arc-minutes)

ERROR SOURCE	**ALLOCATION** RX (ROLL) CROSSTRACK	RY (PITCH) ALONGTRACK	RY DUE TO RZ	RZ (YAW)
RANDOM ERRORS:				
A. S/C CONTRIBUTIONS (Relative between KuPR and KaPR Reference Cubes):				
THERMAL DISTORTION				
LAUNCH SHIFT				
MEASUREMENT ACCURACY				
OBSERVAORY JITTER				
ANALYTICAL UNCERTAINTIES				
TOTAL S/C CONTRIBUTION	**1.000**	**1.000**		**1.000**
B. KuPR INSTRUMENT INTERNAL :				
THERMAL DISTORTION				
LAUNCH SHIFT				
MECHANICAL ERROR/MEASUREMENT ACCURACY				
PHASE ERROR				
ANALYTICAL UNCERTAINTIES				
TOTAL KuPR INSTRUMENT INTERNAL	**2.020**	**3.420**		**6.900**
C. KaPR INSTRUMENT INTERNAL :				
THERMAL DISTORTION				
LAUNCH SHIFT				
MECHANICAL ERROR/MEASUREMENT ACCURACY				
PHASE ERROR				
ANALYTICAL UNCERTAINTIES				
TOTAL KaPR INSTRUMENT INTERNAL	**2.020**	**3.420**		**6.900**
D. ON-ORBIT BEAM MATCHING ERROR				
ESTIMATION ACCURACY OF BEAM LOCATION				
CT PHASE TUNING ACCURACY				
TOTAL BEAM MATCHING ERROR	**1.720**	**1.230**		
T1 RSS of Random Errors	**3.481**	**5.090**		
BIAS ERRORS:				
E. S/C CONTRIBUTIONS (Relative between KuPR and KaPR Reference Cubes):				
SPACECRAFT GRAVITY RELEASE	0.000	0.151	0.151	1.000
SPACECRAFT MOISTURE DESORPTION	0.000	0.076	0.076	0.500
SPACECRAFT RELATIVE KaPR/KuPR PLACEMENT BIAS	0.000	0.453	0.453	3.000
TOTAL SPACECRAFT BIAS:	0.000	0.680		4.500
F. INSTRUMENT CONTRIBUTIONS:				
GRAVITY RELEASE RELATIVE TO BOTH INSTRUMENTS:				
KuPR INSTRUMENT GRAVITY RELEASE	0.000	0.091	0.091	0.600
KaPR INSTRUMENT GRAVITY RELEASE	0.000	0.091	0.091	0.600
MECHANICAL ERROR RELATIVE TO BOTH INSTRUMENTS:				
KuPR MECHANICAL ERROR	0.000	0.453	0.453	3.000
KaPR MECHANICAL ERROR	0.000	0.453	0.453	3.000
MOISTURE DESORPTION RELATIVE TO BOTH INSTRUMENTS:				
KuPR DESORPTION ERROR	0.000	0.076	0.076	0.500
KaPR DESORPTION ERROR	0.000	0.076	0.076	0.500
TOTAL INSTRUMENT BIAS:	0.000	1.239		8.200
T2 Sum of Bias Errors:	**0.000**	**1.919**		
TOTALS:				
T1 **RSS of Random Errors**	3.481	5.090		
T2 **Sum of Bias Errors**	0.000	1.919		
T3 **Sum of Random and Bias Errors**	3.481	7.009		
RSS OF RX AND RY DIRECTIONS=	**7.826**			
ON-ORBIT REQUIREMENTS (1 KM)	**8.447**			
MARGIN (arc-min)	**0.621**			

GSFC responsibility

Instrument responsibility

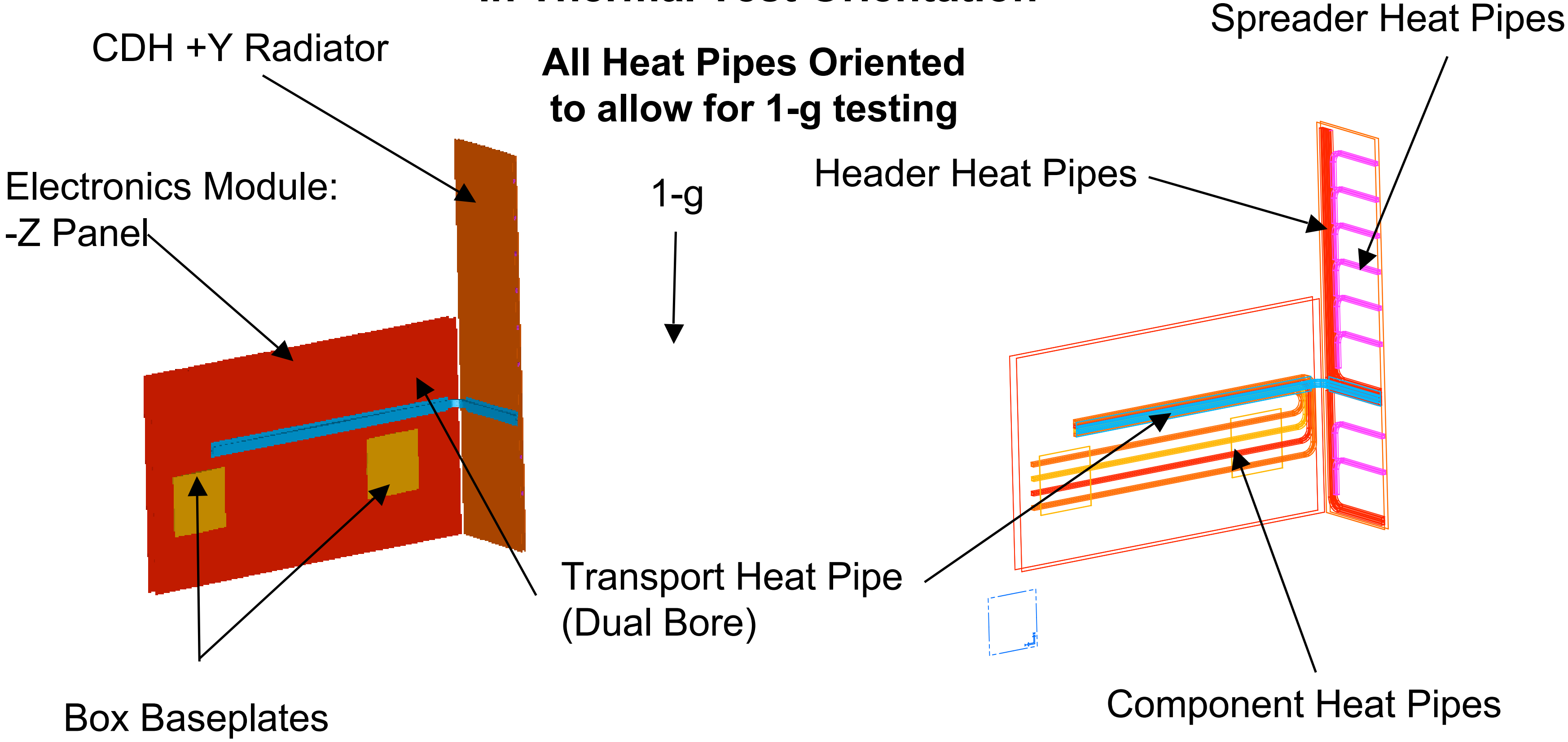
Possible Locations for Thermal Radiators



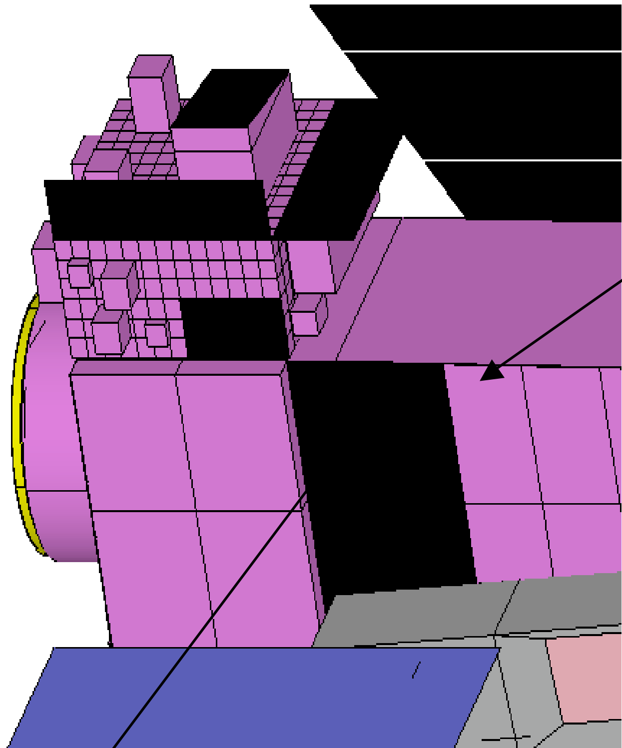
Thermal Heat Pipes

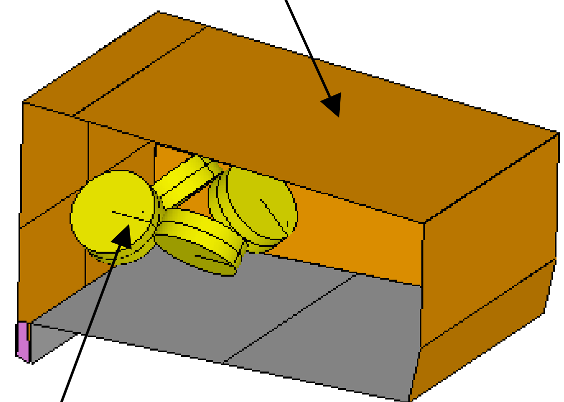
Typical Radiator/Heat Pipe Configuration In Thermal Test Orientation

All Heat Pipes Oriented to allow for 1-g testing



Reaction Wheel TCS





Instrument Support Structure (ISP)

Reaction Wheels, Exterior Surfaces Black

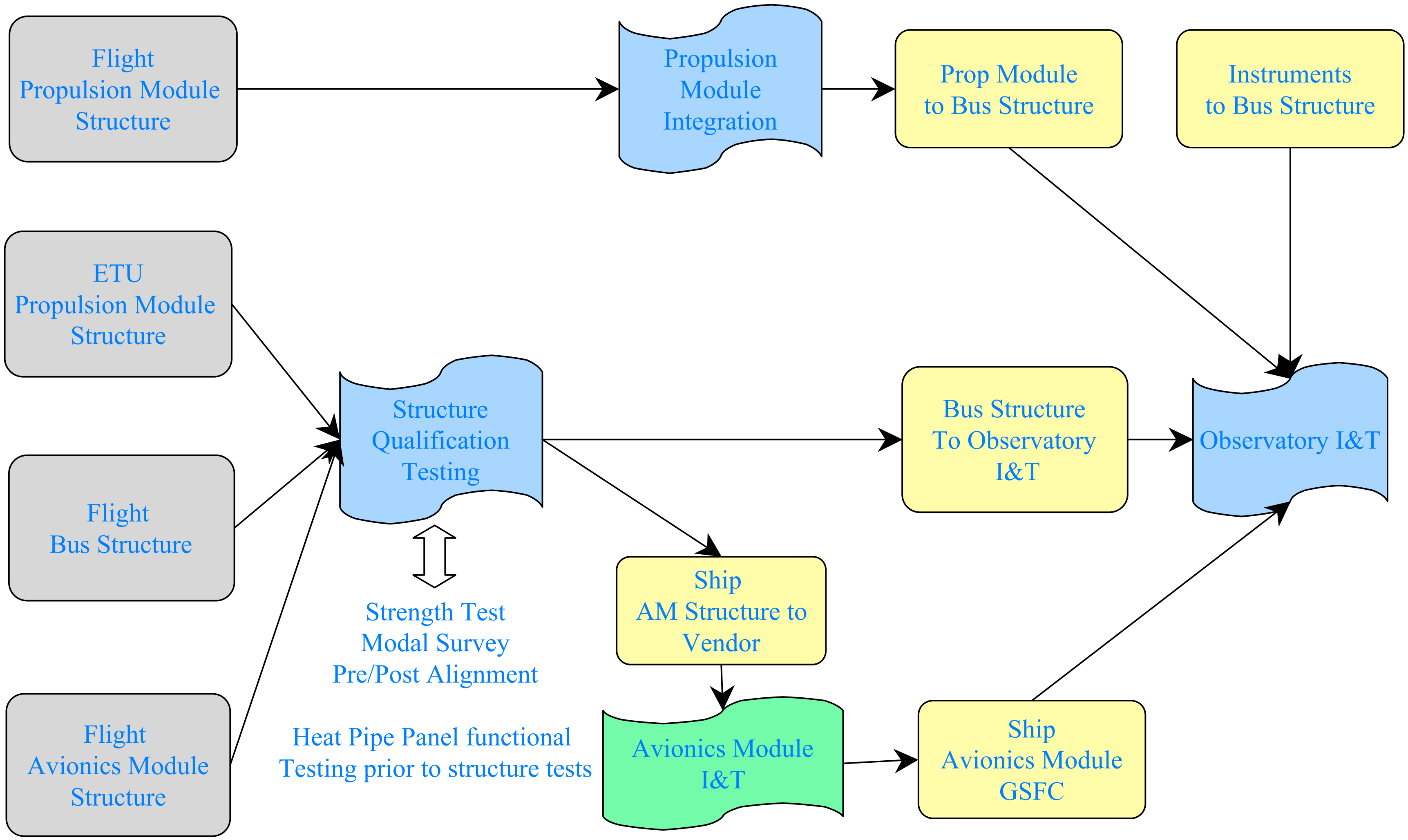
Radiator, Single Layer Material

All Other ISP Surfaces Covered w/MLI

AP Harness Design Requirements

- ***5.5.1.1.4 Electrical Harness Design And Fabrication Requirements***
  - *Wire sizes to be consistent with the current carrying requirements of the circuit*
    - *Minimum wire size (max. gauge) for power and heaters is 22 AWG*
    - *Minimum wire size for signals (max. gauge) is 24 AWG*
    - *Power and power return lines to be twisted pairs without shielding*
    - *Signal lines to be twisted pairs with shielding*
    - *Power harnesses to be routed away from signal harnessing*
    - *Power and signal wires not run in the same bundle shield*
    - *Mechanical support for harnesses to be designed in accordance with NASA-STD-8739.4*
    - *Pyrotechnic harness to be twisted, double shielded cable without any interruptions in the outer shield and with separate pins used for each wire. The connectors must be 360 degree circumferential termination*

GPM Core Observatory I&T Flow-Avionics Integration



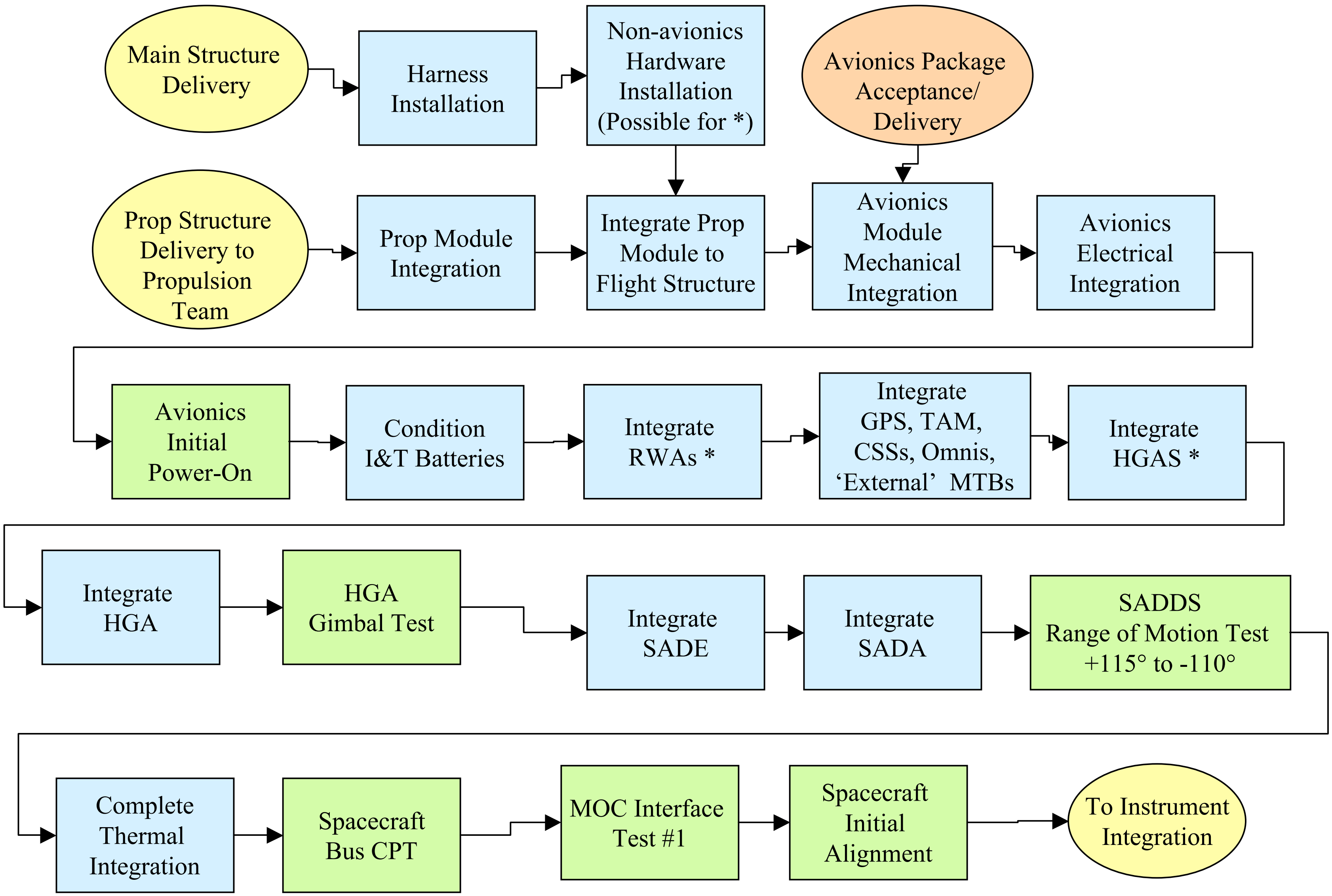
Core Observatory Integration and Test Acronyms and Key

AM – Avionics Module. All of the hardware that is delivered on the Avionics Module Structure
AP – Avionics Package. Includes all hardware and software delivered by the Avionics vendor
CPT – Comprehensive Performance Test
CTV – Compatibility Test Van
CSS – Coarse Sun Sensor
DPR – Dual-frequency Precipitation Radar
ETU – Engineering Test Unit
GMI – GPM Microwave Imager
GPS – Global Positioning System
HGA – High Gain Antenna
HGAS – High Gain Antenna System
I&T – Integration and Test
KaPR – Ka Band Precipitation Radar
KuPR - Ku Band Precipitation Radar
MOC – Mission Operations Center
MTB – Magnetic Torquer Bar
RWA – Reaction Wheel Assembly
SADA – Solar Array Deployment Assembly
SADE – Solar Array Deployment Electronics
SADDS – Solar Array Drive Deployment System
TAM – Tri-Axis Magnetometer

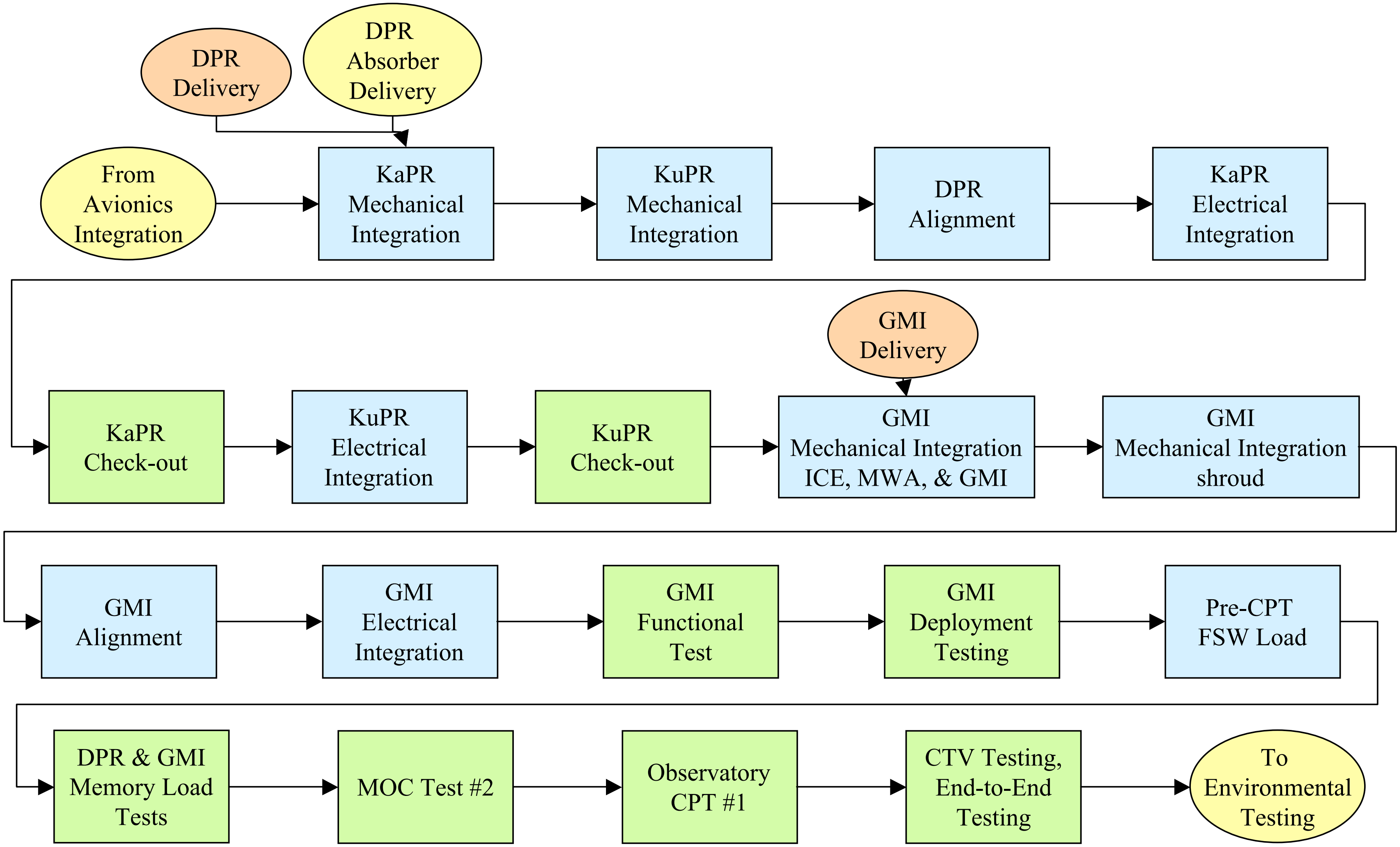
Color Codes for Flow charts:

Yellow: Internal Deliverables	Orange: External Deliverables & JAXA Tasks	Blue: Integration Activities	Green: Tests and Reviews

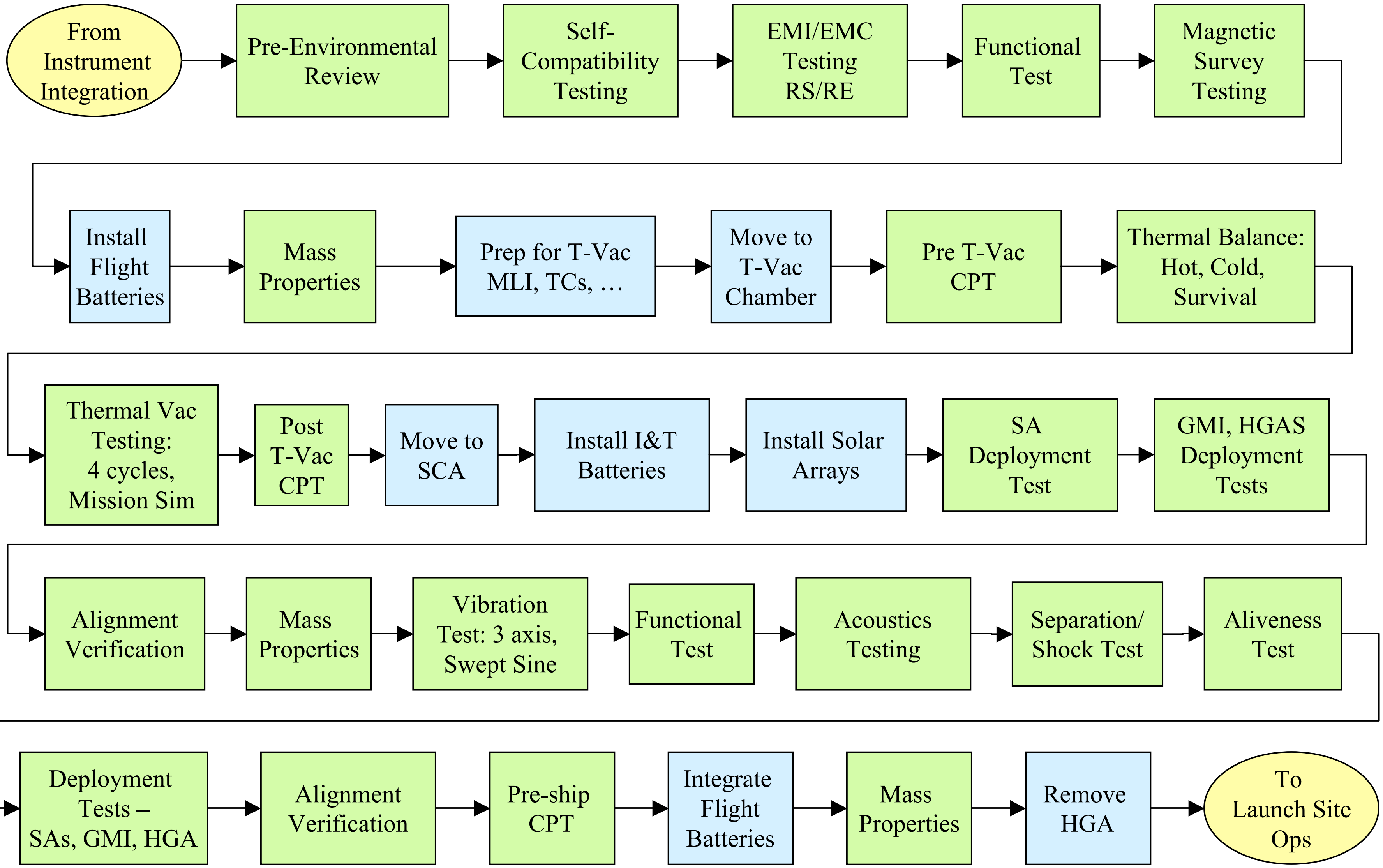
Core Observatory Integration and Test Flow - Avionics Integration



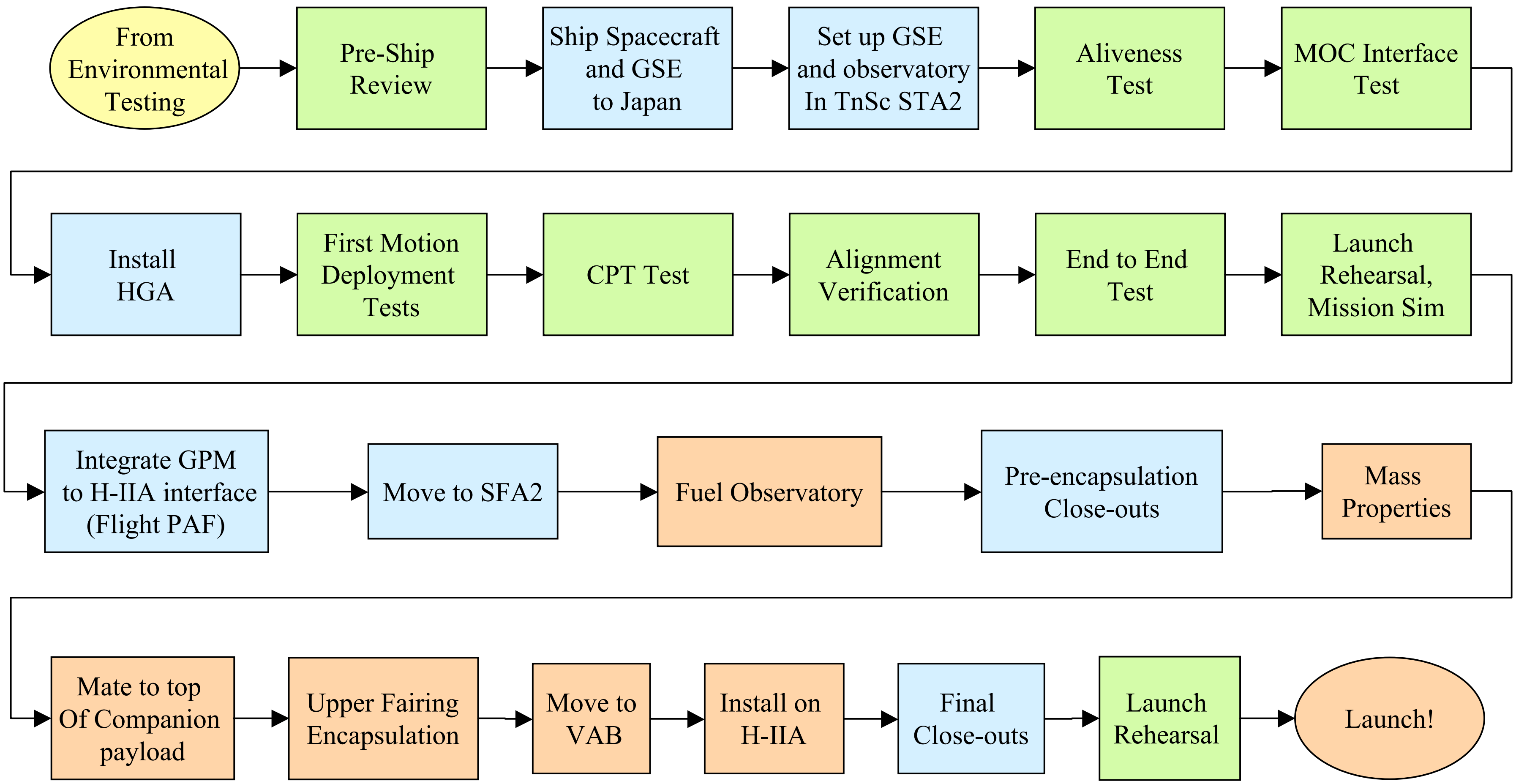
Core Observatory Integration and Test Flow - Instrument Integration



Core Observatory Integration and Test Flow - Environmental Testing



Core Observatory Integration and Test Flow - Launch Site Flow



GLOBAL PRECIPITATION MEASUREMENT

Day 2 - December 7, 2005
Location: NASA GSFC B16W-N76/80

Time	Section	Event	Presenter
8:30 AM	12	Core Spacecraft Management	Horowitz
9:30 AM	13	Primary Spacecraft Systems Engineering	O'Neill
11:00 AM		**Break**	
11:15 AM	14	Mission Operations System Concept/Requirements	Rykowski
12:15 PM		**Lunch**	
1:15 PM	15	Precipitation Processing System Concept/Requirements	Stocker
2:15 PM	16	Ground Validation	Schwaller
3:15 PM		**Break**	
3:30 PM	17	Risk Assessment	Durning
3:45 PM	18	Review Wrap Up	Durning/Ho
4:00 PM		Review Team Caucus	
4:15 PM		**End of Day 2**	